PB81-144479

Phosphorus Removal in Lower Great Lakes Municipal Treatment Plants

Clarkson Coll. of Technology
Potsdam, NY

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Aug 80

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-80-117
August 1980

Research and Development

PB81-144475

EPA

Phosphorus Removal in Lower Great Lakes Municipal Treatment Plants

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TECHNICAL REPORT DATA
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1. REPORT NO. EPA-600/2-80-117	2.	3. RECIPIENT'S ACCESSION NO. PB81 144479
4. TITLE AND SUBTITLE Phosphorus Removal in Lower Great Lakes Municipal Treatment Plants		5. REPORT DATE August 1980 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Joseph V. DePinto, James K. Edzwald, Michael S. Switzenbaum and Thomas C. Young		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Clarkson College of Technology Department of Civil and Environmental Engineering Potsdam, New York 13676		10. PROGRAM ELEMENT NO. PE #35B1C Task C/17
		11. CONTRACT/GRANT NO. R-806817
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 6/79 - 4/80
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
E. F. Barth, Project Officer (513) 684-7641

16. ABSTRACT

This report discusses a survey of phosphorus treatment approaches and accomplishments for all lower Great Lakes basin plants with flows greater than 1 mgd; field operation monitoring studies to evaluate the performance of four municipal treatment plants practicing phosphorus removal, including a determination of the bioavailability of the wastewater phosphorus; and an analysis of costs at each of four plants monitored, including incremental costs to achieve a 0.5 mg/l standard.

Of the 229 plants in this survey, 52 percent are achieving an effluent total phosphorus concentration of 1.0 mg/l, while only 8.3 percent (19 plants) are meeting a 0.5 mg/l standard. If all plants in the Lake Erie basin not currently achieving a 1.0 mg/l standard were to do so, the municipal load would be reduced by 2165 MT/yr. A standard of 0.5 mg/l met in the Lake Erie basin would reduce the current load by 3264 MT/yr. Similar standards achieved in the Lake Ontario basin would reduce municipal loads by 1450 and 2085 MT/yr, respectively.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Wastewater Activated sludge process Chemical removal	Bioavailable phosphorus, Chemical precipitation, Phosphorus removal, Filtration	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 161
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980--657-165/0128

EPA-600/2-80-117
August 1980

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. The complexity of that environment and the interplay between its components require a concentrated and integrated attach on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic efforts of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report addresses the efficacy and desirability of employing a 0.5 mg/L total phosphorus effluent standard for municipal treatment plants in the lower Great Lakes basins.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

PREFACE

The North American Great Lakes contain about 20 percent of the world's supply of surface freshwater and, as such, are indispensible resources worthy of every effort possible to protect and preserve their quality. Over the past ten years the United States and Canada have spent a tremendous amount of time and money in this pursuit. Knowledge has been gained, decisions have been made, goals have been set, and most importantly, significant progress has been made.

With respect to eutrophication control, it has been determined that reducing and restricting phosphorus inputs is the best approach for the Great Lakes. While we feel strongly that there is little question that phosphorus load reductions are necessary for the lower Great Lakes, there is still a debate over the most efficient and economical means to achieve the target loads. This study was conceived to provide some of the data and other information needed to answer several of these questions. The eighteen month review period for the November, 1978 IJC Great Lakes Water Quality Agreement, imposed a definite time constraint on this project. Therefore, based on consultation with our project officer and others in the wastewater research division at MERL, a survey and field study were designed to provide as much useful information on phosphorus removal in the lower Great Lakes municipal treatment plants as possible within the available time frame and resources at our disposal. As a result this report should not be viewed as supplying definitive answers to the questions addressed, but should be used as a source of necessary information in coming to a decision on a phosphorus standard for lower Great Lakes municipal treatment plants.

ABSTRACT

The *Great Lakes Water Quality Agreement* of 1978, established by the International Joint Commission of Canada and the United States called for, among other things, the achievement of 0.5 mg/L total phosphorus as the maximum effluent level in all Lake Erie and Ontario municipal treatment plants discharging greater than one million gallons per day. In order to provide information necessary to review and evaluate the above objective, a study composed of three parts was undertaken: 1) a survey of phosphorus treatment approaches and accomplishments for all lower Great Lakes basin plants with flows greater than 1 mgd; 2) field operation monitoring studies to evaluate the performance of four municipal treatment plants practicing phosphorus removal, including a determination of the bioavailability of the wastewater phosphorus; and 3) an analysis of costs at each of the four plants monitored, including incremental costs to achieve a 0.5 mg/L standard.

Of the 229 plants in our survey 52 percent are achieving an effluent total phosphorus concentration $\leq$ 1.0 mg/L, while only 8.3 percent (19 plants) are meeting a 0.5 mg/L standard. If all plants in the Lake Erie basin not currently achieving a 1.0 mg/L standard were to do so, the municipal load would be reduced by 2165 MT/yr. A standard of 0.5 mg/L met in the Lake Erie basin would reduce the current load by 3264 Mt/yr. Similar standards achieved in the Lake Ontario basin would reduce municipal loads by 1450 and 2085 Mt/yr, respectively.

Most of the plants practicing phosphorus removal add either aluminum or iron as a precipitation cation at some point in the conventional secondary operation. The field studies indicated that a conservatively operated plant using one of the above approaches could achieve an effluent level of $\leq$ 0.75 mg/L, and in some cases lower, without filtration.

Combining all bioavailability assays run on samples from the four plants revealed an average of 72 percent of the total P — 55 percent of the particulate fraction and 82 percent of the total soluble fraction — was available for uptake by *Scenedesmus* sp. Comparison of available P fractions within and among plants suggested that the methods of treatment examined were not selective for available P to the exclusion of non-available P fractions.

This report was submitted in fulfillment of grant number R-806817 by the environmental engineering group at Clarkson College of Technology under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 21, 1979 to March 20, 1980, and work was completed as of April 14, 1980.

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ACKNOWLEDGMENTS

The cooperation and assistance of a great many individuals and agencies were necessary to complete this study. Although they are too numerous to mention individually we would like to thank the treatment plant supervisors and operators who took the time to respond to our rather probing survey questionnaire. Special acknowledgment is due to the gentlemen at the four treatment plants that were highlighted in this study for their total cooperation and hospitality throughout. Mr. Joe Catone, chief operator at the Gates-Chili-Ogden plant; Mr. Mike Schifano, chemist at the Frank Van Lare plant, Mr. Glenn Absolom, Jr., chief supervisor and Mr. Mark Fitzgerald of the Big Sister Creek plant, Mr. James Pastica, plant superintendent and Mr. Terry Jackson at the Ely plant were our major contacts. Of course, the help of all the staff at these plants is greatly appreciated.

A good deal of advice and information was provided by individuals throughout the Great Lakes community; Dr. Edwin Tifft, Jr. and Mr. David Hill, lab supervisor, of O'Brien and Gere Engineers, Inc. conducted the analysis of trace organics in our samples; Mr. Donald Schwinn, Stearns and Wheler, provided valuable assistance on our cost analysis; Dr. William Sonzogni, Great Lakes Basin Commission, Mr. John Archer, Ontario Ministry of Environment, Mr. Ron Drynan, International Joint Commission, Mr. Thomas Quinn and Mr. John Chase of the Monroe County Division of Pure Waters, and Mr. Joe DiMura of the New York Department of Environmental Conservation provided advice and essential information for the study.

Special thanks and acknowledgment is due those students who devoted much time and effort in field and lab analysis to make this project a success; Mr. Kent McManus and Mr. Shawn Veltman spent nearly three months in the field monitoring the four treatment plants; Mr. Steven Flint conducted all the bioavailability work; and Mr. Edward Seger and Mr. Greg Comstock assisted in the heavy metal analysis.

Finally, because of the valuable guidance and active support of certain individuals in the Wastewater Research Division of the Municipal Environmental Research Lab in Cincinnati this project was truly a cooperative agreement. Our special thanks goes to Mr. Edwin F. Barth, Project Officer, for his enthusiasm and insight in planning this project, for his attention to details in our conducting the study and for his thorough review of this manuscript. We also acknowledge the great interest taken in this project by Mr. John J. Convery, Director of the Wastewater Research Division, whose support and advice were invaluable.

SECTION 1

INTRODUCTION

On November 22, 1978 the International Joint Commission (IJC) of Canada and the United States effected the Great Lakes Water Quality Agreement of 1978. Among the many aspects of water quality addressed in the Agreement, the IJC recognized that control of phosphorus in the Great Lakes system was necessary to minimize eutrophication problems. The Agreement denotes a specific objective with respect to phosphorus:

> "The concentration should be limited to the extent necessary to prevent nuisance growths of algae, weeds and slimes that are or may become injurious to any beneficial water use." (IJC, 1978).

Pursuant to the above objective the IJC Agreement established a program to reduce the input of phosphorus to the Great Lakes. The removal of phosphorus from municipal waste treatment discharges was considered an important part of the overall program. In this regard the Agreement called for the achievement by all plants discharging more than one million gallons per day of "effluent concentrations of 1.0 milligram per litre total phosphorus maximum for plants in the basins of Lakes Superior, Michigan, and Huron, and 0.5 milligram per litre total phosphorus maximum for plants in the basins of Lakes Ontario and Erie." (IJC, 1978).

Because of more severe demographic pressure, the lower Great Lakes were considered subject to more severe loading limitations, and hence greater emphasis was placed on control of point sources of phosphorus. Table 1 is a reproduction from the IJC Agreement of the base year (1976) phosphorus loads to the Great Lakes along with target loads recommended by Task Group III (Vallentyne and Thomas, 1978) to meet the Agreement's eutrophication-related water quality objectives. The 1978 Agreement also provided for an eighteen month review to confirm the target loads in Table 1, followed by the establishment of load allocations and compliance schedules. The purpose of this study was to provide information necessary to make recommendations regarding phosphorus load reduction requirements for municipal treatment plants in the lower Great Lakes basins.

It must be noted at this point that the target loads of phosphorus for Saginaw Bay, Lake Erie and Lake Ontario cannot be met by only reducing municipal point source total phosphorus (TP) to 0.5 mg/L. According to the Task Group III report, a 1 mg/L municipal total phosphorus effluent standard for the Erie and Ontario basins would require a concurrent 50 percent reduction in diffuse sources to meet the target loads. A 0.5 mg/L TP

TABLE 1. BASE YEAR AND TARGET PHOSPHORUS LOADS TO GREAT LAKES*

Basin	Base Year (1976) Phosphorus Load (Metric Tons/Yr)	Target Phosphorus Load (Metric Tons/Yr)
Lake Superior	3,600	3,400+
Lake Michigan	6,700	5,600+
Main Lake Huron	3,000	2,800+
Georgian Bay	630	600+
North Channel	550	520+
Saginaw Bay	870	440‡
Lake Erie	20,000	11,000‡
Lake Ontario	11,000	7,000‡

* From IJC (1978)

+ These loadings would result if all municipal plants over one mgd (3,785 m^3/d) achieved an effluent total phosphorus of 1 mg/L

‡ The loadings are required to meet water quality objectives

standard would require a 30 percent reduction in diffuse sources. Assuming the target loads are not changed, a decision must be made regarding the efficacy and cost desirability of the 0.5 mg/L recommended municipal effluent standard for the lower lakes.

There are several questions related to the municipal treatment plant phosphorus standard which were addressed in this study. The current status of municipal treatment plant activities in the lower lakes with respect to phosphorus removal has been evaluated. Such questions as "what are the prevalent approaches being taken to reduce phosphorus effluent concentrations to 1.0 mg/L" and "what technological needs would the treatment plants have to reduce total phosphorus effluent levels to 0.5 mg/L or any point below 1.0 mg/L" have been addressed. Also, there is a need to know the reliability with which full scale treatment operation can operate at the various phosphorus reduction performance levels.

In addition to the technological aspect of establishing a phosphorus treatment regulation for the lower lakes treatment plants, prudent use of the taxpayer's money requires systematic evaluation of the relationship between costs incurred and effluent phosphorus residuals. These costs could then be weighed against the economic and environmental benefits of various phosphorus effluent limitations below 1.0 mg/L. This type of cost analysis at the individual treatment plant level is examined in this study. Costs data gathered in this study can provide crucial information and confirmation of assumptions necessary to make basin-wide cost projections for various municipal phosphorus management programs.

Another important consideration, which is receiving much attention in Great Lakes management and the scientific community, is the question of "phosphorus availability" for the various sources of this material. For virtually every type of phosphorus source there is a certain fraction that is immediately available for algal uptake. The remainder of the total phosphorus in that source contains phosphorus that may be unlikely to ever become available and/or, depending upon its chemical character and the conditions in the receiving water body, will be transformed to a usable form at a certain rate. Projections of lake dynamics in response to phosphorus loads from various sources need to consider, among many other things, the form of the phosphorus in those sources and the rate at which and extent to which each form becomes available for algal uptake. This need applies just as much to municipal point sources as to any other phosphorus source to the Great Lakes. Of particular concern for municipal treatment plant phosphorus is the question of the variability of phosphorus availability with wastewater influent source, conventional treatment approach and specific phosphorus removal measures. This project utilized techniques to bioassay the fraction of phosphorus in municipal treatment plants that can be taken up by algae in a fixed length of time. It should be noted that the results in this phase of the project are only preliminary, and because of time and resources available, could not answer definitively all the questions regarding phosphorus availability in municipal effluents.

In order to address the questions posed in the above discussion, this study contained the following objectives:

1) A desk survey was made of all municipal treatment plants in the lower Great Lakes basins with effluent flows greater than 1 MGD. The purpose of the survey was to evaluate the phosphorus treatment approaches and plant performance and to confirm municipal phosphorus loads.

2) A detailed field operation monitoring program was conducted at four treatment plants practicing phosphorus removal processes representative of lower Great Lakes basin plants. The performance of these plants was evaluated in terms of removal of various phosphorus fractions, reduction of certain priority pollutants, and the overall effluent quality as a function of the phosphorus removal process employed.

3) A detailed analysis of costs incurred at the four selected treatment plants was made for the existing level of treatment. With the existing treatment level costs as a base, estimates were made of costs associated with reducing total phosphorus concentrations to 0.5 mg/L.

SECTION 2

CONCLUSIONS

1. There are 229 municipal treatment plants with discharge greater than 1 mgd (3785 m^3/d) in the two lower Great Lakes basins, representing municipal total phosphorus loads of 4555 metric tons/year to Lake Erie and 2858 metric tons/year to Lake Ontario. Currently 52 percent of the plants in both basins are achieving an effluent total phosphorus concentration $\leq$ 1.0 mg P/L.

2. Of the 229 plants in the lower lakes information on treatment approach was obtained for 134. One hundred and four of the 134 plants responding indicated that they practiced phosphorus removal. Of the plants practicing phosphorus removal 48 percent used aluminum as the precipitation cation while 50 percent used iron. Only two plants practiced phosphorus removal with lime addition. Only 5 percent of the plants utilized some form of tertiary treatment beyond precipitation.

3. Currently 19 treatment plants have been identified as achieving a 0.5 mg P/L effluent concentration. The treatment approach information available on 14 of these plants indicates that only 2 are employing any tertiary processes.

4. The mean influent total phosphorus concentration for 117 municipal plants reporting this value was 6.3 mg P/L. Therefore, on the average 84 percent TP reduction through the plant would be required to achieve 1.0 mg P/L. Of course, these calculations could vary considerably for individual plants. For example, states with phosphate detergent bans (such as New York) tended to have lower influent P concentrations.

5. Based on the results of our survey, if all treatment plants in the Lake Erie basin not currently achieving a 1.0 mg P/L effluent concentration were to do so, the total load to Lake Erie would be reduced by 2165 metric tons/year (13 percent of the current total). A standard of 0.5 mg P/L in Lake Erie would reduce the municipal load by 3264 metric tons/year (19 percent of the current total).

6. For Lake Ontario total load reductions of 11 percent (1450 metric tons/year) and 15 percent (2085 metric tons/year) would be achieved if treatment plants in the basin achieved 1.0 mg P/L and 0.5 mg P/L effluent levels, respectively. These load reductions are conservative in that they do not account for the reduction in the load of phosphorus to Lake Ontario from Lake Erie which would likely result from common standards of phosphorus removal being met simultaneously by wastewater plants in both

basins.

7. Data on phosphorus removal from the four plants which were sampled during this investigation indicate that a final effluent total phosphorus standard of 1.0 mg P/L can be attained with reliability and without filtration, provided that conservative overflow rates are employed during clarification. Though achievement of final total phosphorus concentrations which would meet a 0.5 mg P/L standard appeared to be possible without filtration, as shown by data collected at the Big Sister Creek plant, the reliability with which that standard could be met was uncertain, due to insufficient data. Filtration, as practiced at the Ely plant did appear to provide a reliable technique to attain a 0.5 mg P/L standard.

8. For a specific wastewater the ratio of biologically available phosphorus to total phosphorus remains relatively constant regardless of methods employed for treatment, including phosphorus removal. Thus, the proportionate availability of phosphorus in the raw wastewater determines the fraction of available phosphorus concentration of a wastewater results in a proportionate reduction in the available phosphorus during treatment.

9. Soluble phosphorus is proportionately more available (82 percent) than particulate phosphorus (55 percent) in wastewater. Thus, efforts to control the ecological effects of phosphorus in wastewater effluents should focus, preferentially, on minimizing the soluble phosphorus.

10. It was noted that an effluent level of 0.5 mg/L could be met with the addition of liquid alum to the effluent of the aeration basin of a conventional activated sludge process provided that a conservative operation of the final sedimentation basin, approximately 400 gpd/ft^2 (16.3 m^3/m^2-d), was used.

11. It was noted the alum addition to the primary sedimentation basin was not an effective use of the precipitation cation due to competing reactions with the aluminum.

12. At a tertiary plant, with a well operated solids contact clarifier with $FeCl_3$ and polymer addition, an effluent level of 0.5 mg/L was met without filtration.

13. The operation and maintenance costs associated with phosphorus removal varied significantly for the four treatment plants studied (from $0.007 to 0.107 per 1000 gallons (3.78 m^3) treated) with higher costs at the plants with tertiary treatment. Chemical costs, as opposed to power and labor costs, were the most significant items. The costs associated with sludge production attributed to phosphorus removal were in general not too significant.

SECTION 3

RECOMMENDATIONS

The survey of phosphorus removal performance at wastewater plants in the Lower Great Lakes Basin (LGLB) indicated that average final effluent concentrations of 0.5 mg/L of total phosphorus may be achieved without resort to filtration. It is recommended, therefore, that should a 0.5 mg P/L final effluent standard be placed on municipal treatment plants, then a careful evaluation of less costly, alternative treatment approaches to meet the standard should be performed before resorting to a more expensive filtration process.

The survey showed that the basic approach employed most frequently at wastewater plants in the LGLB to remove phosphorus, in order to comply with present effluent restrictions, amounted to the addition of iron or aluminum salts to the wastewater at some point in a conventional secondary treatment system. Consequently, it is recommended that full-scale studies be undertaken to optimize this approach in terms of the main operational parameters, such as, point of chemical addition and dosage, and further, its integration with standard operating conditions, such as clarifier overflow rates and biological treatment parameters.

With regard to the biological availability of wastewater phosphorus it is recommended that further work be directed toward extensive quantification of availability for wastewaters of differing raw wastewater characteristics, for differing stages of treatment within plants, and among plants which employ different treatment approaches for removal of phosphorus as well as other pollutants. Studies on biological availability should include an analysis of the kinetics of conversion of wastewater phosphorus to available phosphorus, a determination of the fraction of total wastewater phosphorus which ultimately may become available in natural waters, and an examination of the relationship between biologically available phosphorus and chemical measurements of phosphorus.

SECTION 4

METHODS OF INVESTIGATION

GENERAL

This study involved three phases of investigation. The first phase was a desk survey of all municipal treatment plants in the lower Great Lakes basins (Erie and Ontario) with effluent flows greater than 1 mgd (3785 m^3/d). The main objective of this survey was to obtain phosphorus removal process information and to confirm the current phosphorus removal performance at these plants. Concurrently with this phase, a second line of investigation was to conduct field sampling studies at four selected municipal treatment plants. Approximately two weeks were spent at each plant gathering operational data, historical data and cost information. Subsequent to the first two phases of the project, a detailed cost analysis related to the question of phosphorus removal in municipal treatment plants was conducted.

SURVEY METHODS

In order to meet the objectives of the project, it was felt that several important pieces of information had to be gathered on every treatment plant in the Lake Erie and Lake Ontario basins with a discharge flow greater than 1 mgd (3785 m^3/d). Therefore, the following information was obtained for the plants in question:

- Identification of the location of the treatment plant in terms of lake basin, regulatory unit, county, city and receiving water body.
- Identification of type of treatment plant (eg. conventional activated sludge, extended aeration, trickling filter, primary treatment only, etc.)
- Identification of method of phosphorus removal, including point of chemical additions and any tertiary processes associated with P removal (such as filtration, sedimentation, etc.).
- Identification of annual average daily flow and design flow as well as total P concentrations in the raw and plant effluent.

Although much of the above information could be obtained from previous studies, it was felt that certain information could only be reliably obtained directly from the plants. As a result a questionnaire (Appendix A) designed to obtain the above information was sent to a list of 263 municipal treatment plants in the lower lakes basins. The list of plants was compiled from the following sources:

1. International Joint Commission (July, 1978),
2. NYS Dept. of Environmental Conservation (January, 1979),
3. Ontario Ministry of the Environment (December 31, 1977),
4. Great Lakes Basin Commission, Personal Communication (1979).

In addition to providing such otherwise unavailable information as phosphorus removal approach and chemical dosage, the questionnaire provided a current update and confirmation of plant flow and effluent P concentration.

On the basis of the questionnaire, and from other sources of information (see Section 5) when the questionnaire was not answered, a survey work sheet (Appendix A) was prepared for each plant. These work sheets provided the basis for the survey results presented in Section 5. Of the 263 plants sent the questionnaire, 154 returned it with the information requested. Subsequent to mailing the questionnaire, it was determined for a variety of reasons that the actual survey should include only 229 plants. A final list of the survey plants is presented in Section 5.

A special effort was made to obtain the desired information, by telephone if necessary, from all plants with discharge flow greater than 10 mgd (37850 m^3/d). Plants with discharge flow less than 10 mgd (37850 m^3/d) and greater than 1 mgd (3785 m^3/d) which did not answer the questionnaire are not included in certain aspects of the survey results. However, a flow and effluent phosphorus concentration has been assigned to each of the 229 plants, either from questionnaire data or from an independent IJC survey (July, 1979). This was necessary in order to calculate total municipal phosphorus loads to the lower lakes.

MUNICIPAL TREATMENT PLANT MONITORING PROCEDURES

Treatment Plant Section

Four different treatment plants were intensively monitored during the field study phase of this project. The primary criterion for plant selection was that they represented a variety of P removal approaches, including P removal in a primary, a secondary and a tertiary system. Of secondary concern was the logistics of monitoring four different plants for two weeks each, over a period of about two months. It was felt that at least two weeks of data were necessary to smooth out the typical day-to-day fluctuations encountered in the operation of a wastewater treatment plant. It should be noted, however. that the results obtained in this field study represent operational data during summer seasonal conditions. Appendix B contains historical data obtained from each of the four plants so that a perspective can be obtained on seasonal and long-range fluctuations in plant operation.

A brief description of the four intensively monitored treatment plants is presented in Table 2. A more detailed description of each plant, including a process schematic, is given in Section 6.

TABLE 2. PERTINENT INFORMATION ON INTENSIVELY SAMPLED PLANTS

Plant Name and Location	Lake Basin (Regulatory Jurisdiction)	Average Daily Flow (mgd*)	Phosphorus Removal Approach
Gates-Chili-Ogden Plant Rochester, N.Y.	Lake Ontario (New York State)	15	alum addition after secondary aeration tank
Frank Van Lare Plant Rochester, N.Y.	Lake Ontario (New York State)	100	split stream: 1) conventional activated sludge (80 percent of flow); 2) primary only with alum + polymer before primary tank (20 percent of flow)
Big Sister Creek Plant Erie County Sewer Dist. No. 2 Angola, N.Y.	Lake Erie (New York State)	3	tertiary system — $FeCl_3$ + polymer to effluent of secondary clarifier, followed by sand filtration
Ely Plant Ely, Minnesota	Shagawa Lake (Minnesota)	1	alum + polymer added to trickling filter effluent, followed by sedimentation and gravity filtration

* 1 mgd = 3,785 m^3/d

Field Monitoring Procedures

The on-site monitoring phase of the project was performed during July and August of 1979. For the three plants in western New York the field team worked out of a 24 foot (7.3 m) Mobile Environmental Lab (MEL); however, available bench space was used at the Ely plant. During the visit to each plant the following tasks were performed: sample collection; analysis of many parameters on site; shipment of samples for bioassay work and priority pollutant analysis (see below); assessment of plant operation and procurement of historical data on P removal with associated costs; and the gathering of sludge production data for the existing operating mode.

The sample collection involved approximately a 10-12 day period wherein eight-hour composite samples (except for the Van Lare Plant where 24-hour composites were used) were collected from three key locations within each plant, the location of which depended on whether phosphorus removal was a discrete treatment step or integrated with other treatment processes. In all cases the sampling points were selected in order to isolate the effect of the phosphorus removal procedure. The periods of composite sampling at each treatment plant where 8-hour composites were used are presented in Figures 1 through 3.

A flow chart of the analyses performed on the composite samples is presented in Figure 4. Each composite sample was analyzed on-site for chemical oxygen demand (COD), suspended solids (SS), pH, alkalinity, soluble reactive phosphorus (SRP), total phosphorus (TP), total particulate phosphorus (TPP), and the total particulate phosphorus extractable by 0.1 N NaOH (NaOH-P). Less frequently, on-site analyses were performed to determine total Kjeldahl nitrogen (TKN), nitrate and nitrite nitrogen (NO_x), and five-day biochemical oxygen demand (BOD_5). Phosphorus precipitation cations (Al^{3+} and Fe^{3+}) were measured off-site on subsamples taken in connection with the less frequent series of on-site analyses.

A final group of analyses were performed off-site on two or three samples from each sampling location at each plant. Analytical determinations in this group include those for priority pollutants and bioassay of phosphorus availability. The priority pollutants to be measured include both organics and heavy metals (Cd, Zn, Ni). A subcontract to an outside consultant (O'Brien and Gere Consulting Engineers, Syracuse, N.Y.) was used to obtain analyses for organics, while samples for metals were analyzed by project personnel at Clarkson. Bioassay studies of phosphorus availability were performed at Clarkson (procedure described below).

Available Phosphorus Bioassay Procedures

As a verification of the chemical analysis of phosphorus availability in the plant samples, a bioassay of algal-available phosphorus was conducted on selected samples from each plant. While some work has been done on correlating chemical procedures with bioassay measurements of available phosphorus in river water, urban runoff, lake sediments and atmospheric inputs (Cowen and Lee, 1976; Dorich and Nelson, 1978; Fitzgerald, 1970; Goltermann, et al., 1969; Logan, et al., 1979, among others) no such correlations have

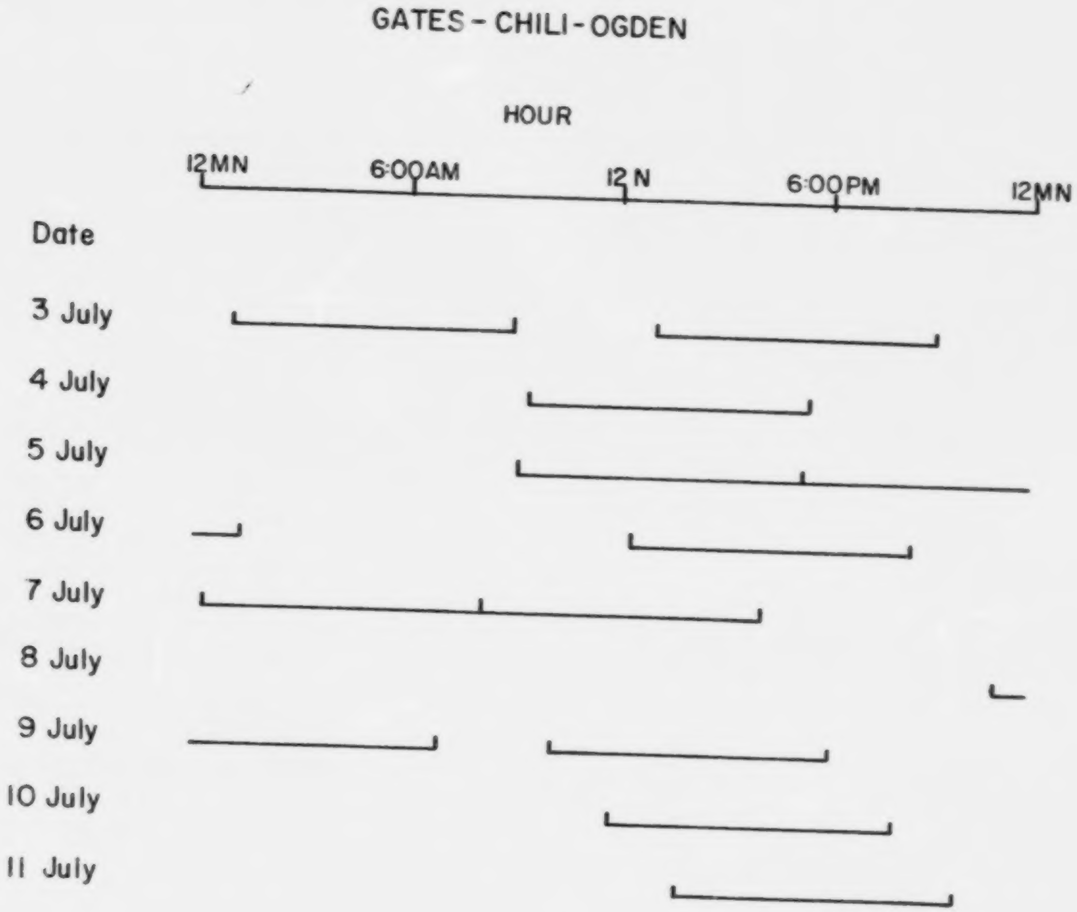

Figure 1. Periods of composite sampling at the Gates-Chili-Ogden wastewater treatment plant, Rochester, NY; July 3-11, 1979

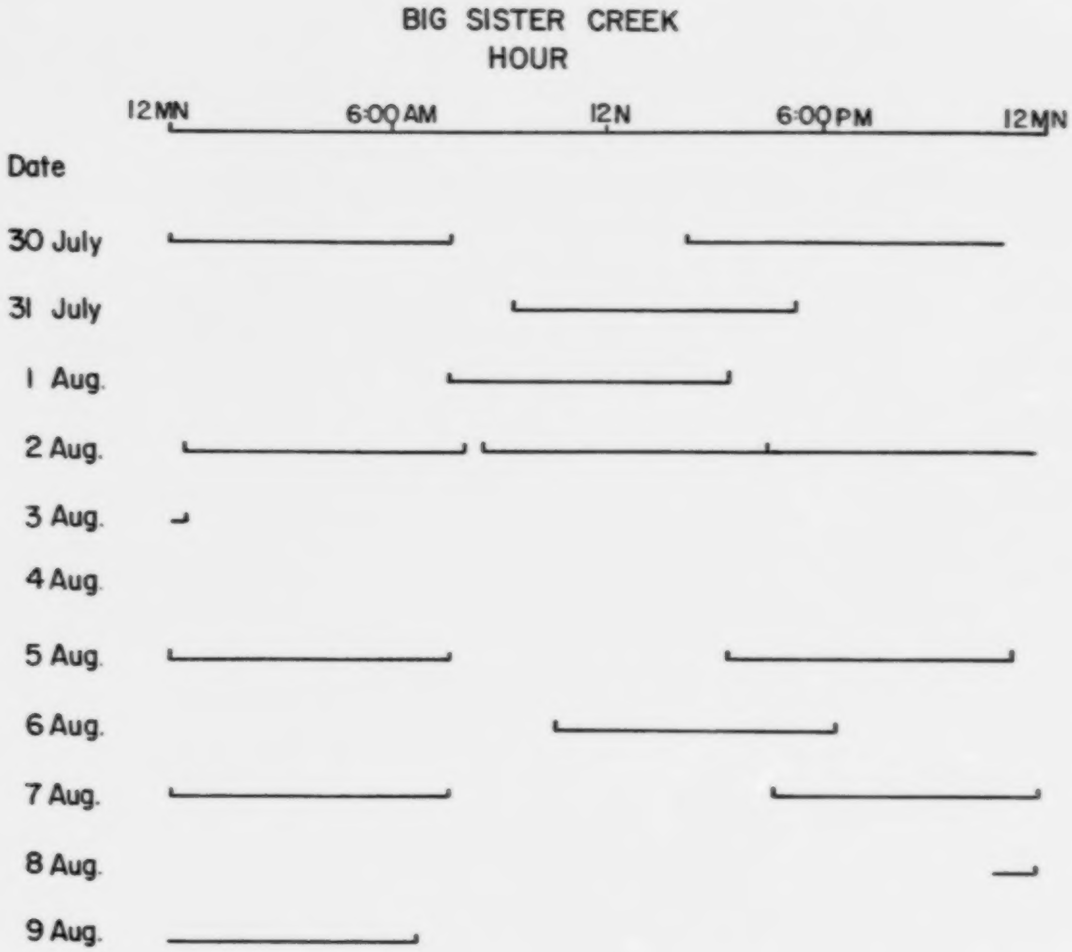

Figure 2. Periods of composite sampling at the Big Sister Creek wastewater treatment plant, Angola, NY; July 30-August 9, 1979

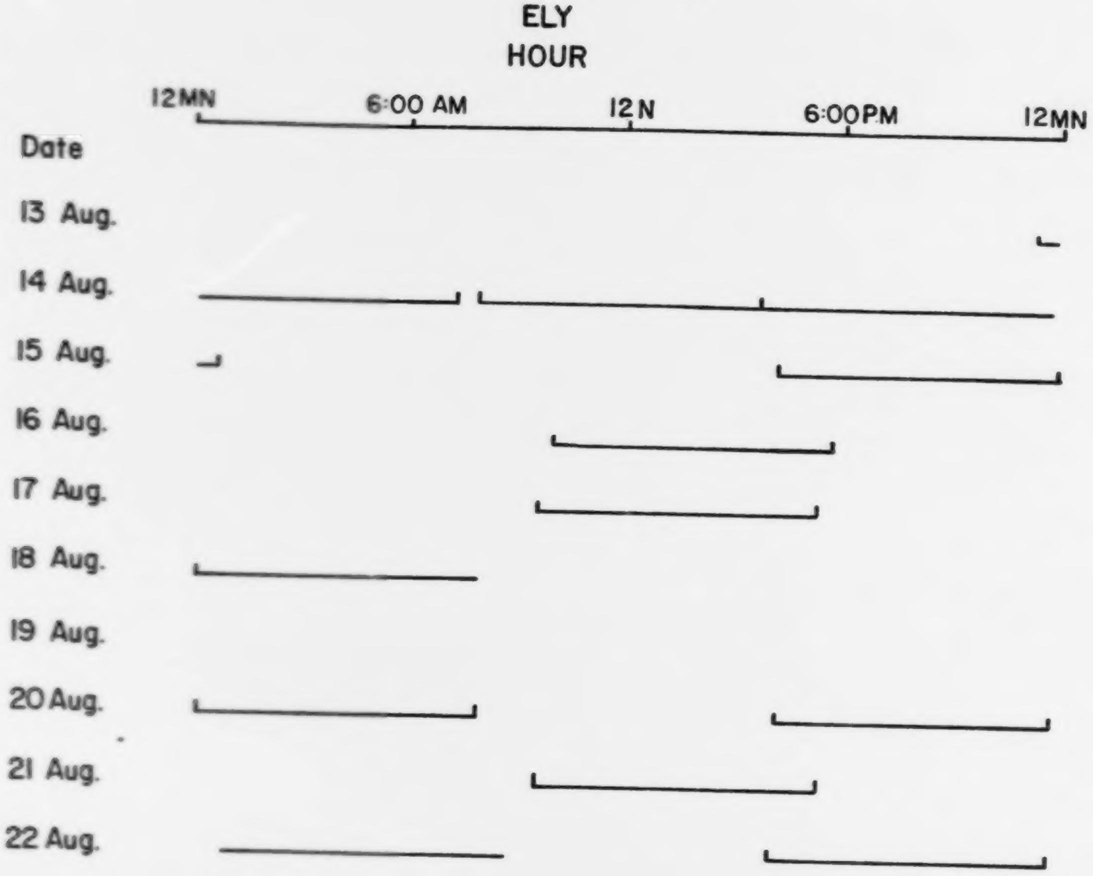

Figure 3. Periods of composite sampling at the Ely wastewater treatment plant, Ely, MN; August 13 - 22, 1979

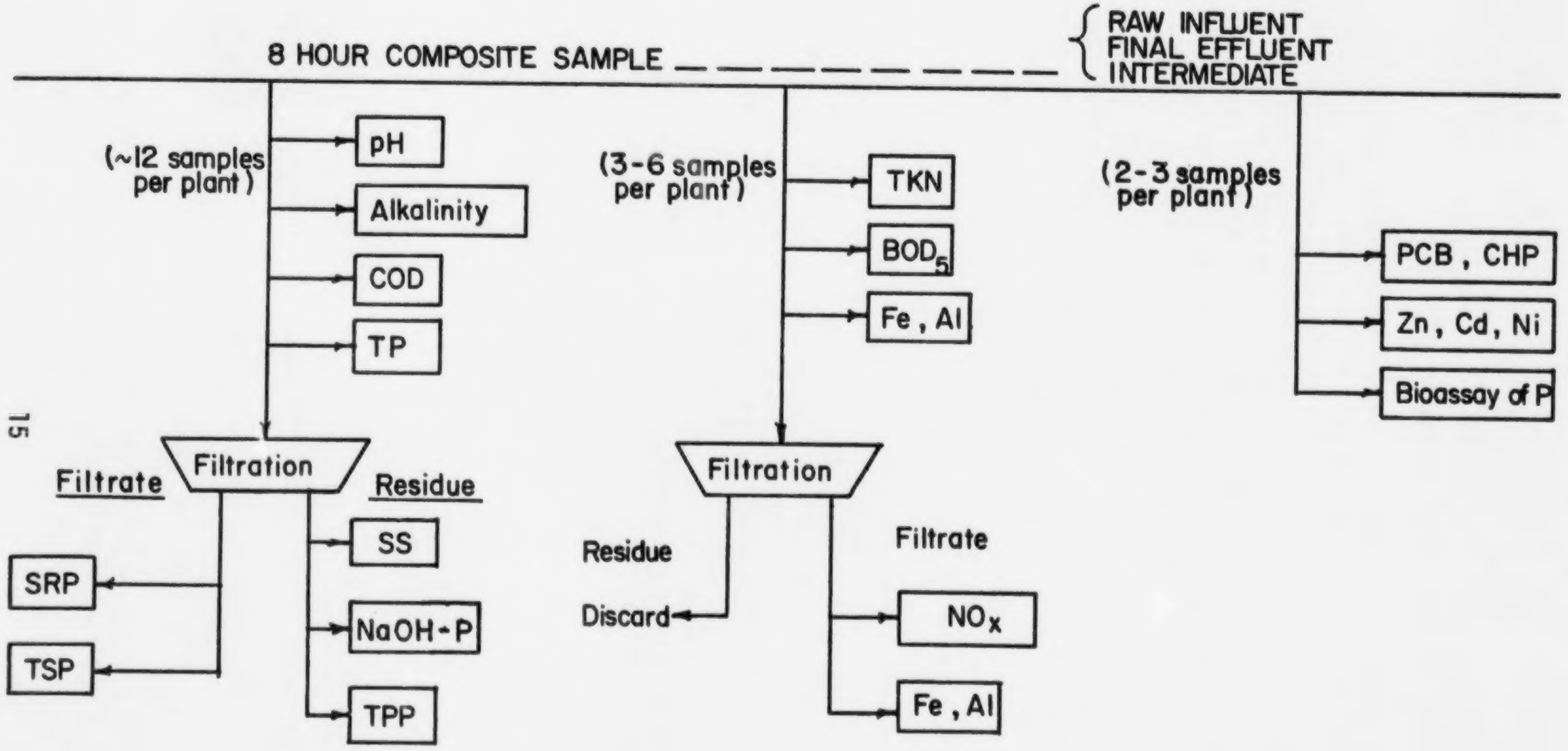

Figure 4. Flow diagram of analytical work on wastewater samples

been published for municipal treatment plants effluents. We, therefore, endeavored to determine what fraction of a plant effluent phosphorus actually has the potential to contribute to algal growth. This information should be valuable in the determination of benefits to be derived from a lower total phosphorus standard for municipal treatment plants.

While it is generally accepted that only a bioassay can be used to measure available phosphorus, the details of the experimental procedures vary widely (DePinto, 1978a). We have selected an approach which employs a direct measurement of phosphorus taken up by a test algal species, thus overcoming the problems associated with indirect estimates relating algal growth to phosphorus uptake. Furthermore, our approach provides for the separation of the assay algae from the particulate material in the plant effluent, which is a prerequisite for direct measurement of algal phosphorus.

Given the above considerations it was determined a dual culture approach similar to that currently being used in our laboratory (DePinto, 1978b) would circumvent many of the problems associated with bioassay determination of available phosphorus from particulates. The apparatus employed (hereafter referred to as a Dual Culture Diffusion Apparatus - DCDA) allows a suspension of particulate matter from plant effluent in a given water medium to be placed in one culture vessel (regeneration vessel) and the placement of a unialgal assay culture (with a known P content) in a separate assay vessel. The two vessels are clamped together but the contents are separated by a 0.4 μm membrane filter (Figure 5). This set-up permits repeated, routine sampling of the algae in the assay vessel without disturbing the particle-water system in the regeneration vessel. The membrane between the two vessels would prevent cross-contamination of particulates but would allow cross-diffusion of soluble material (including P released from the particle-water suspension). Any available phosphorus released by the material in the regeneration vessel will have a tendency to diffuse across the membrane to the assay vessel where it will be rapidly incorporated by the P-starved algae. By periodically sampling the phosphorus content of the assay vessel and performing a mass balance on the system one can determine the extent to which phosphorus is being released by the particulates. Details of DCDA operation and data analysis can be found in McKosky (1978).

A typical bioassay experiment to measure the rate of release of available P from plant effluent particulates is illustrated in Figure 6 and consisted of the following general steps:

1. An aliquot of an 8-hour composite was collected from the treatment plant in question, and a sample of Lake Ontario water was collected from the water intake system at Sackets Harbor, NY (Lake Ontario).

2. The particulate matter in the composite sample was separated from the water by 0.45 μm membrane filtration. The Lake Ontario water sample was also filtered through a 0.45 μm membrane filter.

3. A complete chemical characterization was performed on the treatment plant sample as described in the previous section.

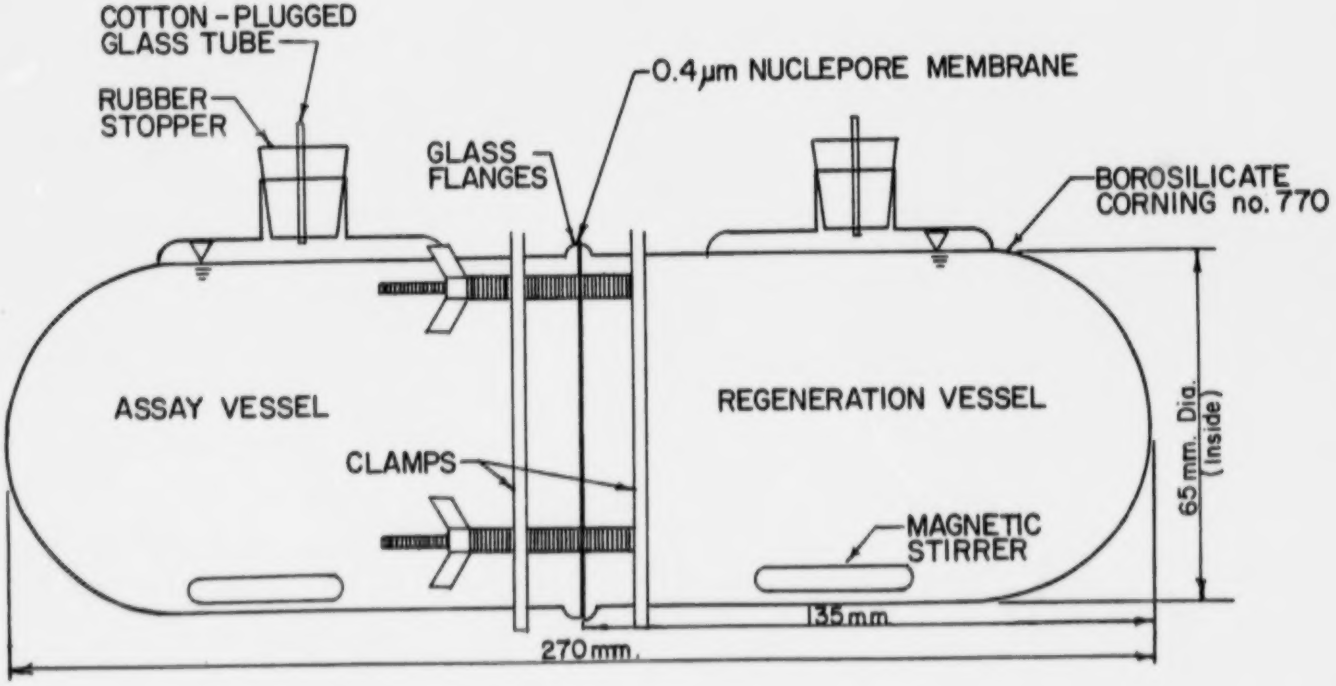

Figure 5. Dual culture diffusion apparatus for particulate phosphorus bioassay tests

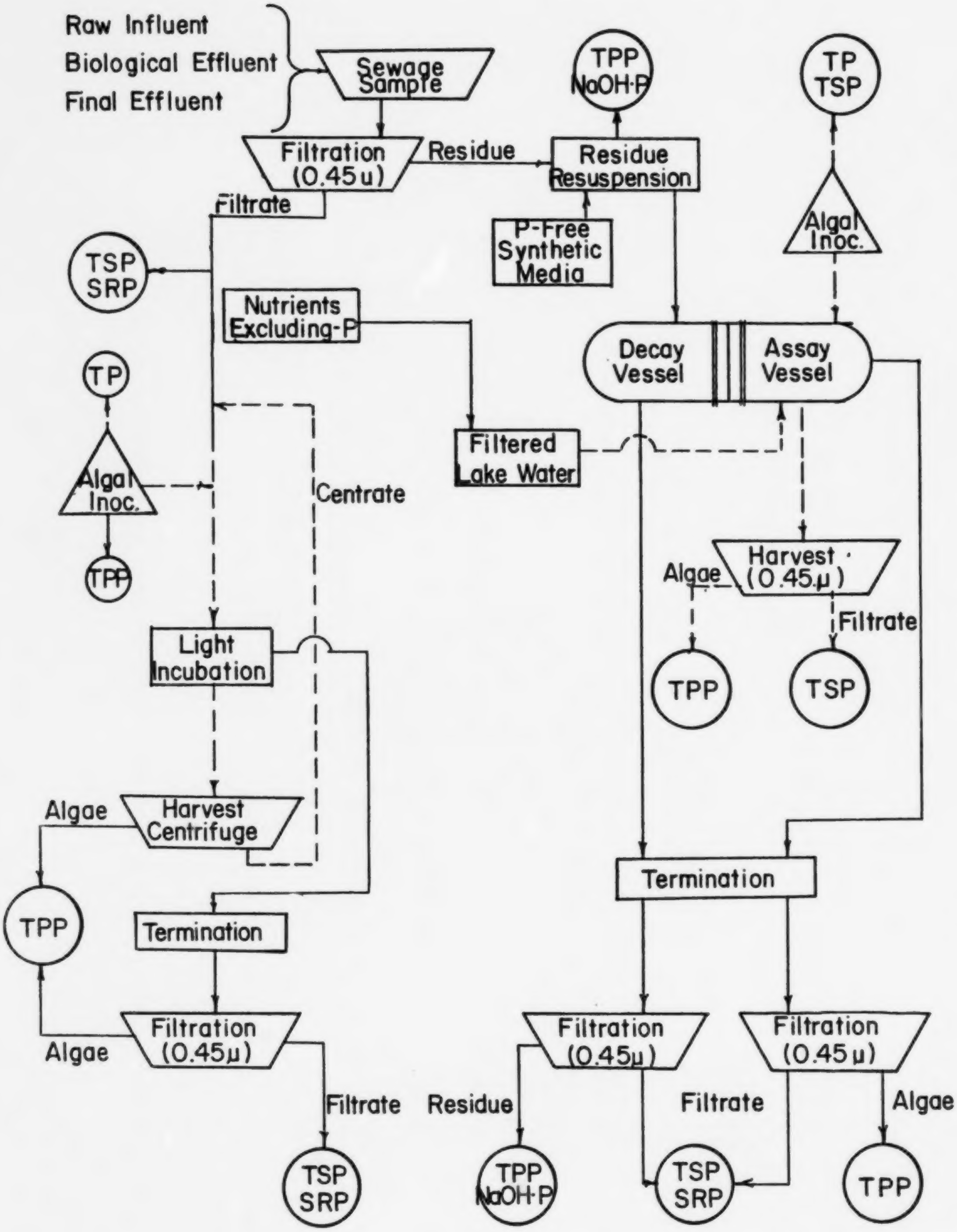

Figure 6. Flowchart of available phosphorus bioassay

4. The sample particulate matter, suspended in P-free synthetic algal medium, was placed in the darkened regeneration vessel of the DCDA. The lighted assay vessel contained a P-starved Scenedesmus culture in the filtered lake water.

5. The contents of each vessel were continuously stirred and the assay vessel was periodically sampled for phosphorus to determine the accumulation of released available P in the algae.

6. After a suitable incubation period (two weeks to a month) the run was terminated and both sides of the DCDA were reanalyzed for the same parameters as the initial characterization.

In addition to the above analysis on the suspended solids in the plant effluent, a bioassay of algal available P was performed on the "soluble" fraction of the effluent collected in step 2 above. A number of authors have pointed out possible discrepancies between chemical methods (such as the soluble reactive P test) and actual algal available phosphorus (Chamberlain and Shapiro, 1969; Peters, 1977). To bioassay the fraction of total "soluble" (less than 0.45 μm) phosphorus in these samples that is available for algal uptake, a simple sequential batch uptake experiment was performed according to the following general procedure:

1. The 0.45 μm filtrate of a treatment plant sample was diluted with P-free synthetic algal medium to a total soluble phosphorus concentration of 300 μg P/L. The diluted sample was inoculated with a P-starved test algae inoculum (of known P content) and incubated in a lighted environment with continuous stirring.

2. After a suitable incubation period (2-5 days), a separation of the test algae from the water sample was obtained by differential centrifugation, which left colloidal and soluble material in the supernatant. An analysis was made of the new total P content of the separated algae.

3. A new inoculum of P-starved test algae was added to the supernatant sample and step 2 was repeated.

4. Steps 2 and 3 were repeated until no increase in test algal cell phosphorus content was noted.

5. The total available phosphorus in the original sample was then the summation of the phosphorus taken up in each sequential incubation.

ANALYTICAL METHODS

For the most part the analytical methods used in this study are described in Standard Methods (APHA, 1975) and/or recommended by EPA (1976). The routine analytical methods are described and referenced in Table 3. Additionally, the determination of total NaOH-extractable phosphorus fraction of non-filterable residue was made by an extraction method similar to that of Sagher, et al. (1971) followed by total phosphorus determination

TABLE 3. PHYSICAL AND CHEMICAL METHODS OF ANALYSIS

Parameter	Method	Reference
pH	Electrometric, combination electrode	APHA (1975) Part 424
Alkalinity	Electrometric titration	APHA (1975) Part 403
Suspended Solids	Gavimetric @ 103°C	APHA (1975) Part 208D
Chemical Oxygen Demand	Standard ampule method, acid-dichromate oxidation	Oceanography International (1978)
Phosphorus	Ascorbic acid colorimetric	APHA (1975) Part 425F
Total Kjeldahl Nitrogen	Acid Digestion; distillation; phenate colorimetric	Scheiner (1975)
NO_3+NO_2-N	Cadmium reduction; chromatropic acid colorimetric	HACH Chemical Co. (1975)
Biochemical Oxygen Demand	Dilution bottle test; polarographic oxygen measurement	APHA (1975) Part 507
Iron	Nitric acid digestion; flame atomic absorption	EPA (1976)
Aluminum	Nitric acid digestion; eriochrome cyanine-R colorimetric	APHA (1975) Part 302B
Cadmium, Nickel and Zinc	Nitric acid digestion; carbon rod atomic absorption	EPA (1976)

of the filtered extract.

The forms of particulate phosphorus which are extractable by a variety of solutions including 0.1 N NaOH have been discussed by several workers; for example, Armstrong et al. (1971), Cowen and Lee (1976), and Williams et al. (1971). These investigators have indicated that the phosphorus removed from particulate matter by 0.1 N NaOH consists of inorganic and organic phosphorus which is bound by a gelatinous matrix consisting of colloidal organics and amorphous oxides and hydroxides of iron and aluminum which coat the surfaces of the particulate. Studies by Sagher (1976) and Wildung et al. (1977) have indicated the inorganic component of the NaOH-extractable particulate phosphorus to be that which is most readily available to algae. Inasmuch as the particulates of interest in the present investigation were from municipal wastewaters and, thus, contained relatively labile organic phosphorus, it was decided to measure the total particulate phosphorus extractable by NaOH for comparison with bioassay tests of particulate phosphorus availability to algae.

Organic contaminants (PCB's and chlorinated pesticides) measured by O'Brien and Gere were determined by hexane extraction followed by gas chromatography with electron capture detection.

SECTION 5

RESULTS OF SURVEY AND PHOSPHORUS LOADINGS TO LOWER LAKES

INTRODUCTION

In order to evaulate present conditions regarding phosphorus loadings and treatment removal strategies in the lower Great Lakes Basins, a survey was conducted of all municipal treatment plants with flows greater than 1 mgd (3785 m^3/day) in the drainage basins of Lakes Erie and Ontario. Originally, a list of plants was put together as a mailing list for a questionnaire. The mailing list for the questionnaire was compiled from lists provided by the following agencies: 1) IJC, 2) Ontario Ministry of the Environment, 3) Great Lakes Basin Commission and 4) New York State Department of Environmental Conservation. The following information was requested from each of the wastewater treatment plants:

1) treatment plant name and address
2) type of plant
3) average daily flow and design flow
4) method of phosphorus removal
5) influent and effluent phosphorus concentrations
6) chemical dosages for phosphorus removal

A copy of the questionnaire and cover letter is presented in Appendix A.

The questionnaire information was checked and supplemented with additional data from the same agencies used for compiling the mailing list. Finally, the data were transferred to work sheets, a copy of which is shown in Appendix A.

The questionnaires served as the major source of information for the survey. Originally 268 were mailed to plants in the lower lakes basins. Five turned out to be duplicates, thus 263 plants were covered in the mailing. The number of responses received was 154. Supplemental information was then collected for the plants which did not respond, as well as for verification of the respondents. A recent IJC report (July 1979) and other sources (NYS Dept. of EnCon, 1979; IJC, 1977; Ontario Ministry of the Environment, 1977) were used for verification and augmentation of questionnaire data.

A master list of the treatment plants in the lower Great Lakes Basins is presented in Table 4. The breakdown of the number of plants by drainage basin and country is detailed in Table 5. Note that 229 plants are included in the master list. The final number is less than the 263 questionnaires

TABLE 4. MASTER LIST OF PLANTS

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Lake Ontario - New York State:					
Amherst SD #6	8.4	45.3	3.9	1	yes
Auburn STP	10.5	26.1	1.8	1	yes
Avon STP	1.2	0.6	0.4	1	yes
Batavia STP	2.9	46.4	11.4	3	no
Brewerton STP	1.2	2.3	1.4	1	yes
Buffalo SA STP	192	142.8	2.8	1	yes
Canandaigua	2.4	2.0	0.6	2	yes
Canastota STP	1.4	-	-	2	yes
Carthage West STP	3.7	2.6	0.5	1	yes
Cayuga Heights STP	1.5	1.9	0.9	2	no
Cheektowaga SD STP #5	10	-	-	1	yes
Dansville STP	1.4	1.4	0.7	1	yes
East Aurora STP	2.0	3.7	1.3	2	no
Fulton STP	4.1	21.2	3.7	3	no
Davis Road STP	3.4	20.4	4.3	2	yes
Geneseo STP	0.7	1.7	2.5	1	yes
Geneva Marsh STP	2.6	11.4	3.1	1	yes
Ithaca STP	8.0	21.1	1.9	2	yes
Tonawanda STP #2	16	11.1	0.5	1	yes

(continued)

TABLE 4. (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Tonawanda STP City	4.7	18.6	2.9	3	no
Lackawana STP	3.3	10.0	2.7	1	yes
Oneida STP	1.2	5.5	3.3	1	yes
Lowville STP	1.1	9.9	6.9	2	no
Watertown	8.0	51.1	4.6	2	no
Oswego West Side STP	4.0	-	-	3	no
Oswego East Side STP	2.2	2.6	0.8	2	no
Oak Orchard STP	1.7	-	-	4	no
Wetzel Road STP	4.2	53.8	3.4	2	no
Meadowbrook STP	6.0	15.5	1.9	2	no
Syracuse Metro STP	58.4	223.6	2.8	2	yes
Ontario Water Util Dept.	0.4	1.3	2.6	1	yes
Newark STP	2.0	4.2	1.5	1	yes
Seneca Falls STP	1.8	6.3	2.6	2	yes
Pen Yan STP	1.0	-	-	1	yes
Lakeville STP	0.5	0.2	0.5	1	yes
NW Quad (Monroe Co)	12.5	12.1	0.7	1	yes
Webster STP	2.0	-	-	1	yes
Webster Central STP	1.5	10.0	4.9	1	yes
Rochester - GCO	20.0	21.8	0.9	1	yes
Rochester - Van Lare	100	124.4	1.0	4	no
Henrietta STP	2	-	-		

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Wellsville STP	1.0	2.1	1.5	1	yes
Lewiston STP	0.4	0.3	0.5	1	yes
Niagara Falls STP	60	107.8	1.4	1	yes
Newfane STP	0.8	0.9	1.0	1	yes
Niagara City SD STP #1	19.4	297.5	11.1	3	no
North Tonawanda STP	5.9	20.2	2.5	1	yes
Lockport STP	11	11.9	0.8	1	yes
Lake Ontario - Ontario Province:					
Port Colborne West STP	2.5	3.1	0.9	2	no
Port Colborne East STP	1.8	2.5	1.0	2	no
Orangeville STP	2.0	2.5	0.9	2	no
Dundas STP	2.0	3.1	1.1	2	no
Niagara Falls (Stamford)	9.1	13.5	0.9	1	yes
Hamilton STP	54	179.2	2.0	1	yes
Welland STP	9.0	6.5	0.5	1	yes
Baker Road STP	1.6	1.7	0.6	1	yes
Port Weller STP	7.8	7.9	0.3	1	yes
Port Dalhovsie STP	7.3	3.9	1.0	1	yes
Southeast STP	2.0	3.3	1.0	1	yes

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Oshawa Harmory Creek	7.5	9.3	1.0	1	yes
Harmon Creek WPCP	7.5	21.8	2.0	1	yes
Tuclor Lane	1.8	-	-	5	no
Pugsley WPCP	2.1	3.2	1.1	2	no
Frenchman Bay STP	2.3	2.5	0.8	2	no
Southwest STP	8.3	16.1	1.4	2	no
Milton STP	1.8	4.4	1.8	2	no
Drury Lane STP	1.8	2.3	0.9	2	no
Pringle Creek STP	2.5	3.0	0.8	2	no
Cobourg STP	3.6	6.9	1.4	2	no
Highland Creek	31.8	47.4	0.9	1	yes
Toronto, North STP	8.5	11.4	0.8	1	yes
Toronto Humber STP	71.3	100.3	0.8	1	yes
Toronto, Main STP	168	206.3	0.7	1	yes
Lindsay STP	2.0	3.9	1.2	1	yes
Peterborough STP	10.3	22.2	1.3	1	yes
Port Hope STP	1.7	2.4	0.8	1	yes
Lakeview STP	40	66.4	1.0	1	yes
Skyway STP	18.8	31.9	1.0	1	yes
Campbell Ford STP	1.3	2.1	1.0	1	yes
Clarkson STP	11.5	16.2	0.8	1	yes
Ajax STP	2.2	4.1	1.1	1	yes

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Bownanville STP	1.4	2.1	0.9	1	yes
Corbett Creek STP	3.5	30.2	5.2	1	yes
Georgetown STP	2.2	3.3	0.9	1	yes
Belleville STP	9.1	12.6	1.0	2	no
Napanee STP	1.3	7.5	3.5	1	yes
Trenton STP	3.0	3.6	0.8	1	yes
Fort Erie	3.0	7.4	1.8	2	0
Kingston Twp STD	2.5	3.3	1.0	2	0
Trenton CFB	1.5	0.8	0.4	2	0
Markham	1.4	1.8	0.9	2	0
Lake Erie - New York State					
Erie Co. DPW SD #2	3.1	3.4	0.8	1	yes
Erie Co. SD #2 STP	4.4	8.1	1.3	3	no
Amherst SD #1	5.8	34.5	4.3	1	yes
Hamburg Master SD	2.6	6.1	1.7	2	no
Gowanda STP	1.2	4.7	2.8	3	no
Westfield Village STP	1.4	1.3	0.7	1	yes
Fredonia STP	3.0	1.9	0.7	1	yes
Dunkirk STP	5.2	3.6	0.5	1	yes

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Hamburg	1.7	-	-	2	0
Springville	1.0	-	-	2	0
Pennsylvania					
Erie STP	58.1	112.4	1.4	1	yes
Indiana					
Decatur STP	1.4	0.8	0.4	1	yes
Ft. Wayne STP	30.0	20.7	0.5	1	yes
Auburn STP	1.9	1.2	0.5	2	no
Michigan					
Monroe STP	12.0	2.5	0.2	1	yes
Tecumseh STP	1.1	13.8	9.1	2	no
Adrian STP	3.4	24.5	5.2	2	yes
Saline STP	1.4	4.9	2.6	2	no
Ann Arbor STP	17.1	18.9	0.8	1	yes
Ford Lake	5.9	5.7	0.7	1	yes
Brighton STP	0.8	0.9	0.8	1	yes

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Rochester STP	1.5	-	-	2	no
Pontiac STP	20.0	8.3	0.4	1	yes
Gross Isle Twp STP	2.5	-	-	2	no
Detroit	801	1992.2	1.8	1	yes
Wayne Co Flat Rock STP	2.9	3.9	1.0	2	no
Wayne Co Trenton STP	5.1	10.5	1.5	2	no
Wayne Co - DWP STP	80	105.0	1.0	1	yes
Mt. Clemens	1.1	24.8	15.9	2	no
Warren STP	32	35.4	0.8	1	yes
St. Clair STP	1.5	5.2	2.5	1	yes
Marine City STP	1.1	1.8	1.2	2	no
Marysville STP	2.6	2.5	0.7	2	no
Port Huron STP	12	13.6	0.8	1	yes
Trenton STP	6.2	14.9	1.7	2	0
Ypsilanti CU	5.4	10.6	1.4	2	0
Ypsilanti Util	9.5	12.5	1.0	2	0
Lake Erie - Ontario					
London-Adelaide STP	2.9	6.7	1.4	1	yes
London-Greenway STP	24.3	28.2	0.7	1	yes

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
London-Vauxhall STP	4.4	5.8	0.8	1	yes
London-Oxford STP	1.0	1.0	0.8	1	yes
London-Pottersburg STP	3.1	4.6	0.9	1	yes
Windsor-Little River STP	5.5	5.2	0.6	1	yes
Leamington STP	1.7	2.0	0.7	1	yes
Wallaceburg	1.0	1.2	0.9	1	yes
Stratford STP	4.0	4.0	0.6	1	yes
Port Dover STP	1.3	1.8	0.8	1	yes
Chatham STD	5.2	7.8	0.9	1	yes
St. Mary's STP	0.8	0.6	0.6	1	yes
St. Thomas STP	5.0	7.5	0.9	1	yes
Belle River STP	0.8	0.6	0.6	1	yes
Ingersoll STP	1.4	1.1	0.6	2	no
Amherstburg STD	1.1	3.1	2.1	2	no
Sarnia STD	10.6	11.6	0.9	2	no
Woodstock STP	5.6	6.9	0.9	2	no
Tillonsburg STP	1.6	0.7	0.4	1	yes
Dresden STP	1.5	5.3	2.5	2	no
Windsor-Westerly STP	21.4	29.8	0.8	1	yes
Hespeler	1.2	1.1	0.7	2	no
Kitchener STP	15.8	26.3	1.2	2	no
Crystal Beach STP	8.6	14.4	1.0	1	yes

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Guelph STP	9.2	15.3	1.0	1	yes
Waterloo STD	6.0	8.0	0.8	1	yes
Galt STD	6.0	8.0	0.8	1	yes
Simcoe STP	2.4	2.8	0.7	1	yes
Preston STP	1.8	2.4	0.8	1	yes
Brantford STD	10.2	16.1	1.0	1	yes
Fergus STP	0.9	1.0	0.9	1	yes
Dunnville STP	1.2	0.8	0.5	2	0
				2	0
Lake Erie - Ohio					
Ashtabula STP	4.5	7.5	1.2	1	yes
Conneaut STP	2.2	2.4	0.8	1	yes
Lake Co. Madison SD	1.5	2.8	1.4	2	no
Lake Co. Menter SD	6.3	19.1	2.2	2	no
Painesville STP	4.0	16.7	3.0	2	no
Willoughby-E. Lake	7.1	7.8	0.8	1	yes
Kent STD	2.6	17.2	4.7	2	no
Ravenna STP	1.8	4.0	1.6	2	yes
Portage Co STP	1.6	4.8	2.2	1	yes
Macedonia SD #15	1.5	-	-	3	no

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Twinsburg	1.3	1.4	1.0	1	yes
Akron	85	205.5	2.0	1	yes
Cleveland-Southly	97.5	444.6	3.3	1	yes
Cleveland-Easterly	130	106.0	0.6	1	yes
Cleveland-Westerly	30.6	173.4	4.1	1	yes
Rocky River STD	11.1	19.7	1.3	2	no
Breckville STP	1.2	0.8	0.4	2	no
Euclid STP	19.1	148.6	5.6	3	no
Lakwood STP	12.3	11.9	0.7	2	no
Bedford Heights STP	2.5	3.9	1.1	2	no
Berea STP	2.0	18.2	6.6	3	no
Middleburg Hts. STP	2.5	3.4	1.0	1	yes
North Olmstead STD	5.8	4.8	0.6	1	yes
Bedford STP	2.3	12.9	5.0	1	yes
Chargrin Falls STP	0.8	1.1	1.0	1	yes
Strongsville STD	1.5	9.5	4.6	2	no
Solon STP	1.6	39.4	17.8	2	yes
Maple Heights STP	0.8	0.7	0.8	1	yes
Medina Co STP 100	1.5	11.4	5.6	2	no
Medina Co STP 200	2.2	12.4	4.1	2	no
Medina Co STP 500	1.6	5.8	2.6	2	no
Avon Lake STP	4.6	5.7	0.9	2	no

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Amherst STP	1.3	3.3	1.9	2	no
French Creek STP	1.7	1.5	0.6	1	yes
Oberlin STP	1.2	2.2	1.2	1	yes
Lorain STP	15	19.5	0.9	1	yes
Elyria STP	8.2	35.0	3.1	1	yes
Sandusky STP	8	10.0	0.9	1	yes
Upper Sandusky STP	10.2	11.7	0.8	3	no
Vermilion STP	1.5	11.3	5.3	2	no
Goodrich Road STP	0.8	7.1	6.0	1	yes
Willard STP	1.0	6.2	4.4	1	yes
Norwalk STP	2.0	9.0	3.2	2	no
Bucyrus STD	2.8	23.2	6.0	1	yes
Tiffin STP	3.8	3.5	0.7	2	no
Fostoria STP	4.5	6.5	1.0	1	yes
Clyde STP	1.0	7.2	5.5	1	yes
Fremont STP	5.0	3.4	0.5	1	yes
Port Clinton STP	1.6	0.7	0.3	2	no
Perrysburgh STP	1.2	1.5	0.9	1	yes
Bowling Green STP	4.0	5.5	1.0	1	yes
Findlay STP	7.6	17.4	1.7	1	yes
Wapakoneta STP	1.6	27.6	12.1	1	yes
St. Mary's STP	1.1	-	-	3	no

(continued)

TABLE 4 (continued)

Plant	Average Daily Flow (mgd*)	Total P Load (Metric Tons/Yr)	Effluent Total Phosphorus (mg/L)	Source for P and Flow Data	Response to Questionnaire
Lima STP	12.6	11.8	0.7	1	yes
Ottawa STP	0.8	7.2	6.1	1	yes
Napoleon STP	1.8	-	-	3	no
Maumee River STP	5.6	9.6	1.2	2	no
Toledo STP	90	135.6	1.1	1	yes
Wauseon STP	0.6	7.8	9.4	1	yes
Archbold STP	1.6	9.3	4.1	2	no
Montpelier STP	0.9	16.1	10	1	yes
Bryan STP	1.7	28.6	12.2	2	no
Defiance STP	3.8	5.2	1.0	1	yes
Van Wert STP	2.9	4.9	1.2	2	no
Oregon STP	2.8	8.9	2.3	2	0
Medina Co. 300	3.5	5.8	1.2	2	0
Summit Co. 5	1.4	8.5	4.6	2	0
Summit Co. 6	8.0	16.3	1.5	2	0

* 1 mgd = 3,785 m^3/d

(continued)

TABLE 4 (continued)

Source References

1. Questionnaire
2. Inventory of Major Municipal and Industrial Point Source Discharges in the Great Lakes Basin. International Joint Commission, Great Lakes Water Quality Board Remedial Programs Subcommittee, July 1979.
3. Great Lakes Water Quality 1977, Appendix C. Remedial Programs Subcommittee, International Joint Commission, Great Lakes Water Quality Board, 6th Annual Report, July 1978.
4. Descriptive Data of Sewage Treatment Plants in New York State. New York State Department of Environmental Conservation, January 1, 1979.
5. Water and Wastewater Treatment Works in Ontario. Ontario Ministry of the Environment, December 31, 1977.

Questionnaire Response

yes = answered questionnaire
no = did not respond
0 = was not sent a questionnaire (added later to master list)

TABLE 5. NUMBER OF PLANTS IN SURVEY

Lake Ontario				
New York	48		U.S.	48
Ontario	43		Canada	43
	91			
Lake Erie				
New York	10		U.S.	106
Pennsylvania	1		Canada	32
Indiana	3			
Michigan	23			
Ohio	69			
Ontario	32			
	138			
		Totals:	U.S.	154
			Canada	75
				229

mailed out. A number of plants, 48, were removed from the list for one of several reasons. Among these were: 1) the plants were abandoned; 2) the plants were not actually in the lower lakes basins (i.e. were discharging into the St. Lawrence River or Huron basin); and 3) the flows were less than 1 mgd (3785 m^3/d). Data from questionnaires received from plants with actual flows less than the 1 mgd limit were not discarded, and the plants were included on the master list. This was done in order to keep the information regarding phosphorus removal strategies for subsequent analysis. Finally, 14 plants were later added to the list after the initial mailing. Thus, 229 plants are included on the master list.

Where more than one source of data existed for one plant, priority was given to the questionnaire data. The 1979 IJC report was then used for plants with no questionnaire data, if the data were available from the report. Finally for plants on the list for which neither the questionnaire nor the IJC report contained data, the other sources listed above were used.

TREATMENT APPROACHES FOR PHOSPHORUS REMOVAL

Based on the results of the questionnaire, the treatment approaches for phosphorus removal at wastewater plants in the Great Lakes vicinity can be listed. One hundred and four plants indicated that phosphorus removal was being practiced at the present time, while 30 indicated that phosphorus removal was not practiced. An additional 20 plants were eliminated from those who responded due to their location or abandonment. Thus, from the questionnaire responses approximately 80 percent of the plants used for the survey practiced phosphorus removal.

A summary of the major chemicals used for phosphorus removal and their point of addition in the treatment process (i.e. primary, secondary or tertiary) is shown in Table 6. Of the 104 plants practicing phosphorus removal, 53 used an iron salt (one more than shown in Table 6 as one respondent listed iron but did not specify where), 49 used an aluminum salt, and only two used lime. One plant used both iron and alum. A comparison of frequency of the precipitation cation used (aluminum or iron) by country is shown in Table 7. In comparison, Fe or Al are used with about the same frequency. Lime is now seldom used based on our survey. In regard to point of treatment, the data are summarized in Table 8.

From Table 6, it can be seen that approaches for phosphorus removal include aluminum addition to the secondary process, iron addition to primary, and iron addition to secondary processes, in order of decreasing frequency of use.

PHOSPHORUS REMOVAL DATA

Frequency of Phosphorus Effluent Concentrations

Based on the master list developed from our survey (Table 4), a frequency distribution was developed for 30-day average effluent phosphorus concentrations in the lower lakes basins. This distribution is summarized in Table 9 and illustrated in Figure 7. Of the plants in Table 4 that

TABLE 6. TREATMENT APPROACHES BY CHEMICAL (PRECIPITATION CATION) AND LOCATION

	Number of Plants								
	U.S.			Canada			Total		
	Al	Fe	Total	Al	Fe	Total	Al	Fe	Total
Primary	1	16	17	2	20	22	3	36	39
Secondary	26	6	32	17	8	25	43	14	57
Tertiary	2	2	4	1	0	1	3	2	5
Total	29	24	53	20	28	48	49	52	101

TABLE 7. FREQUENCY OF PRECIPITATION CATION USAGE

	Percent		
Metal	U.S.	Canada	Total
Al	54	41	48
Fe	44	57	50
Lime	2	2	2

TABLE 8. SUMMARY OF LOCATION OF PHOSPHORUS REMOVAL TREATMENT IN THE TREATMENT PLANT PROCESS

Process Location	Percent		
	U.S.	Canada	Total
Primary	32	46	39
Secondary	60	52	56
Tertiary	8	2	5

TABLE 9. FREQUENCY OF 30-DAY AVERAGE EFFLUENT PHOSPHORUS CONCENTRATIONS - mg/L AS TOTAL P

Range of TP, mg P/L	Number of Plants*		
	U.S.	Canada	Total
$0<TP\leq0.5$	14	5	19
$0.5<TP\leq1.0$	39	54	93
$1.0<TP\leq1.5$	21	8	29
$1.5<TP\leq2.0$	10	4	14
$2.0<TP\leq2.5$	6	2	8
$2.5<TP\leq3.0$	10	0	10
$3.0<TP\leq3.5$	6	1	7
$3.5<TP\leq4.0$	2	0	2
$4.0<TP\leq4.5$	6	0	6
$4.5<TP\leq5.0$	6	0	6
$5.0<TP\leq5.5$	3	1	4
$5.5<TP\leq6.0$	4	0	4
$TP>6.0$	12	0	12
			214

*Phosphorus effluent data were not available for 7 plants in the Erie basin and 8 plants in the Ontario basin

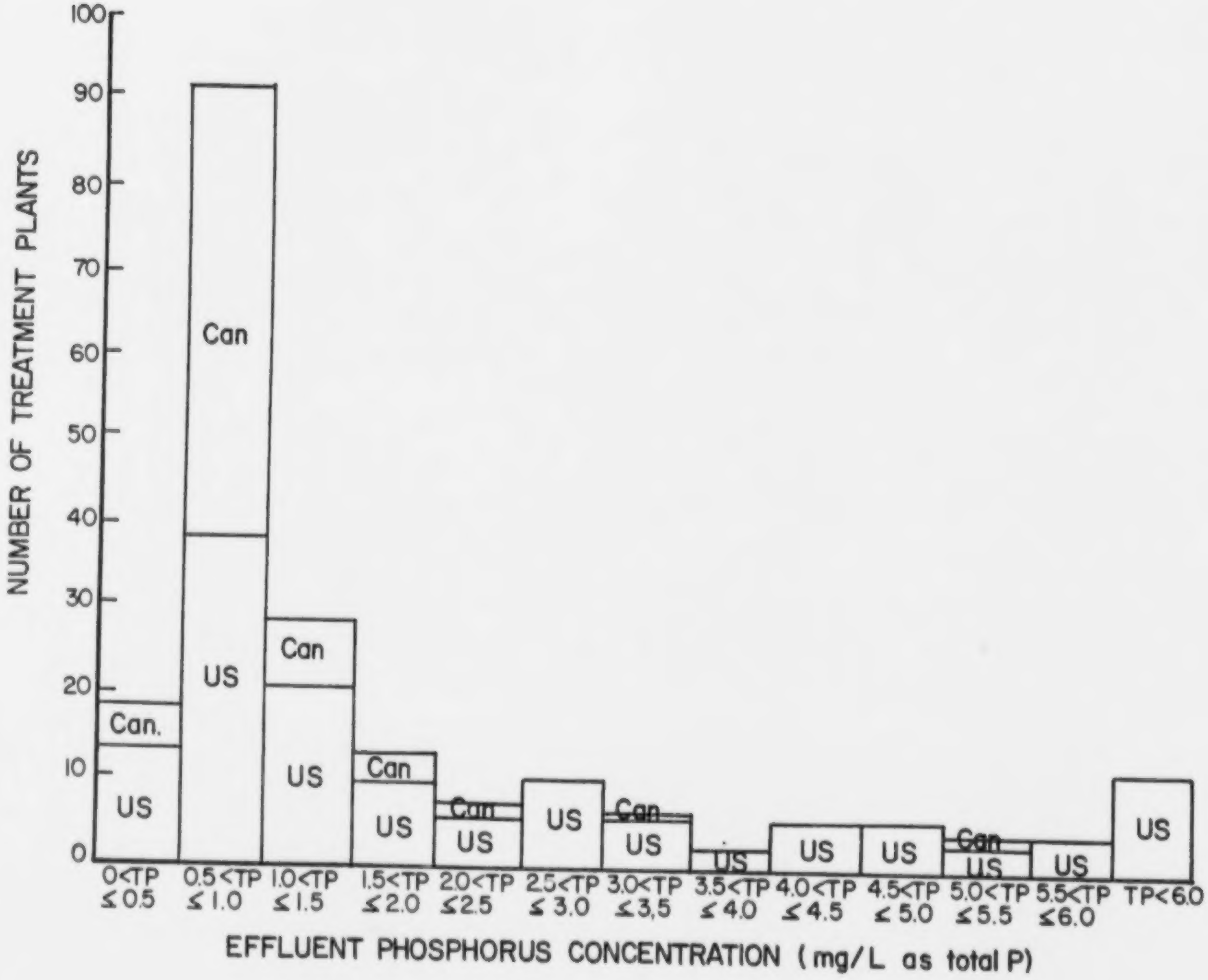

Figure 7. Histogram of effluent phosphorus concentration in lower Great Lakes plants

listed effluent P, 9 percent have an effluent TP concentration $\leq$ 0.5 mg P/L and 52 percent are $\leq$ 1.0 mg P/L. The distribution of these plants by size and lake basin is given in Table 10. Currently, 62 plants in the Lake Erie basins (47 percent) do not meet a 1.0 mg P/L effluent phosphorus standard, while 40 plants in the Lake Ontario basin (48 percent) are failing to meet the standard. There does not appear to be any major trends by plants size in the fraction meeting a 1.0 mg P/L standard; however, plants in the 10 to 50 range seem to be doing comparatively better than the others.

Whether required or not, there are 19 plants in the basins currently meeting a 0.5 mg P/L standard. We received a questionnaire response, and therefore have treatment approach information, on 14 of these 19 plants. It is especially interesting to note that only 2 of the 14 plants are currently employing any tertiary treatment processes. Seven of the plants use $FeCl_3$ (some also use a polymer) or pickle liquor at some point in the treatment process; four of the plants use alum; and three plants claim to achieve 0.5 mg P/L with no chemical addition simply because the influent phosphorus is low (1-2 mg P/L).

Frequency of Percentage Removal Achieved

In order to get some feel for what percentage removals are currently needed to meet todays effluent phosphorus standards, a frequency distribution of removal percentage was prepared from our questionnaire data. These results are presented in Table 11 and in Figure 8. Note that only 117 plants made up the sample for this distribution, since both influent and effluent data were necessary to compile removal percentages. Recall that approximately 80 percent of the respondents to the survey were practicing phosphorus removal, yet only 63 percent of those reporting influent and effluent phosphorus levels were achieving 80 percent removal of total phosphorus through the plant. Virtually all (96 percent) of the plants which reported removals of 80 percent or more of influent phosphorus were using iron or aluminum for precipitation during treatment. Only 68 percent of all the plants which employed chemicals for phosphorus removal, however, were achieving percent removals of 80 or better. This result suggests two possibilities: either the treatment plants do not generally have to remove 80 percent of the phosphorus to meet 1.0 mg P/L effluent concentration, or there is room for improvement in many plants as far as phosphorus removal efficiency is concerned. Since 47 percent of the plants are failing to meet 1.0 mg P/L, it seems likely that the latter case is most prevalent.

According to our questionnaire the mean influent phosphorus concentration to plants in the lower lakes is 6.3 mg P/L. This means that on the average 84 percent TP reduction through plant would be necessary to achieve a 1.0 mg P/L effluent standard and 92 percent TP reduction would be necessary to achieve a 0.5 mg P/L effluent concentration.

PHOSPHORUS LOADING TO THE LOWER LAKES

Based on the survey results, current loadings of total phosphorus from municipal point sources are presented in Table 12. Additionally, Table 12 contains projected phosphorus loadings which would result if all plants

TABLE 10. DISTRIBUTION OF PLANTS BY SIZE AND BASIN REACHING 1.0 and 0.5 mg P/L TOTAL PHOSPHORUS EFFLUENT CONCENTRATIONS

Plant Size (mgd)*	No. of Plants in Size Range**	Plants Meeting 1.0 mg P/L Standard	Plants Meeting 0.5 mg P/L Standard
		Lake Erie	
<1	12	6	0
1-<10	94	47	8
10-<50	18	14	3
50-<100	5	1	0
≥100	2	1	0
Total	131	69	11
		Lake Ontario	
1	5	3	2
1-<10	60	29	5
10-<50	11	8	1
50-<100	4	1	0
≥100	3	2	0
Total	83	43	8

* 1.0 mgd = 3,785 m^3/d

** Phosphorus effluent data were not available for 7 plants in the Erie basin and 8 plants in the Ontario basin

TABLE 11. FREQUENCY OF PERCENT PHOSPHORUS REMOVAL ACHIEVED (BASED ON TOTAL PHOSPHORUS; DATA FROM QUESTIONNAIRE)

Range, Percent	Number of Plants		
	U.S.	Canada	Total
0-<10	6	0	6
10-<20	1	0	1
20-<30	1	0	1
30-<40	3	0	3
40-<50	4	0	4
50-<60	10	3	13
60-<70	8	2	10
70-<80	7	4	11
80-<90	17	28	45
90-100	9	14	23
			117

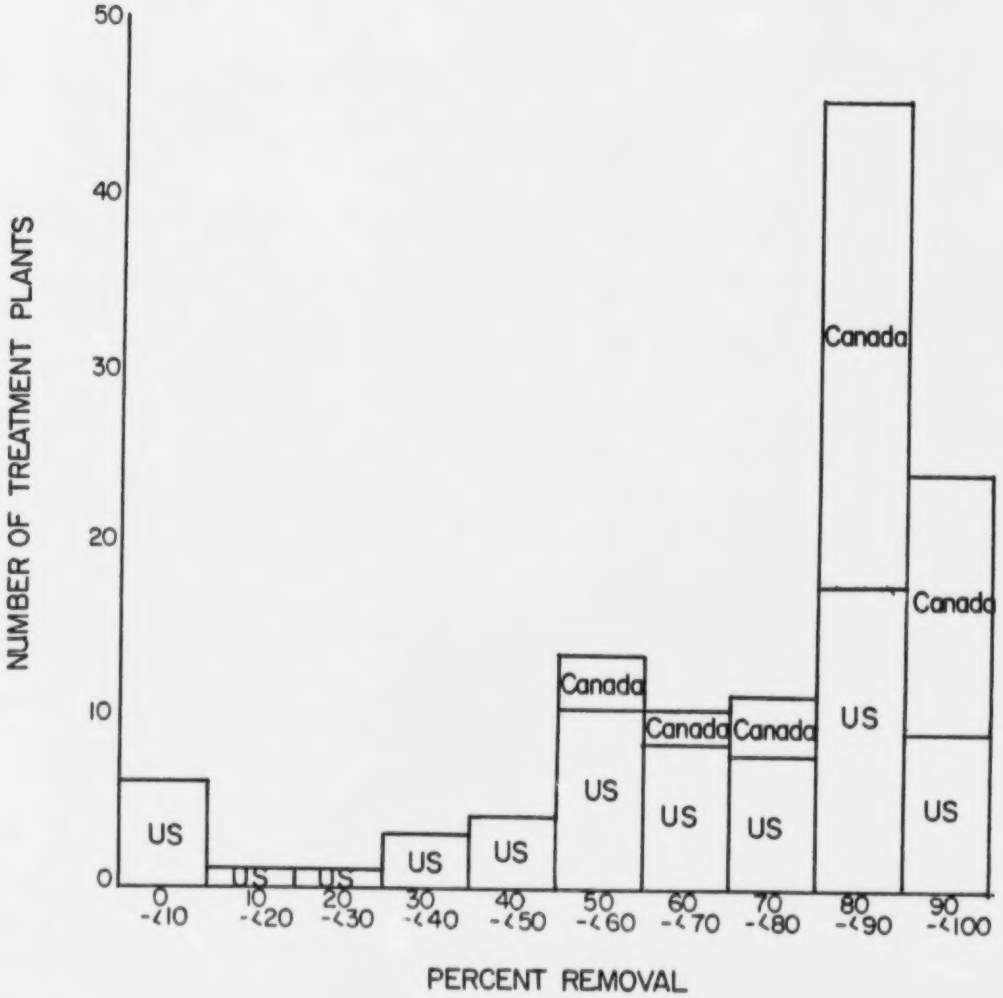

Figure 8. Histogram of phosphorus percentage removals in lower Great Lakes plants

TABLE 12. PRESENT AND PROJECTED MUNICIPAL POINT SOURCE PHOSPHORUS LOADINGS TO THE LOWER GREAT LAKES - IN METRIC TONS/YEAR

		Projected Loadings	
Lake Ontario	Present Loading*	1.0 mg/L	0.5 mg/L
New York	1973	783	406
Ontario	885	625	367
	2858	1408	773
Lake Erie			
New York	64	33	18
Pennsylvania	112	80	40
Ohio	1812	705	395
Indiana	23	23	23
Michigan	2312	1356	701
Ontario	232	193	114
	4555	2390	1291
Total	7413	3798	2064

* For all plants above 1 mgd (3,785 m^3/d)

which presently exceed 1.0 or 0.5 mg P/L effluent concentrations were to achieve the respective levels. All calculations were based on loads reported on the master list, Table 4, and assume that phosphorus acts conservatively between the points of effluent discharge and entry to the lakes. The data in Table 12 indicate that should all plants larger than 1 mgd (3785 m^3/d) achieve the level of 1.0 mg P/L, the municipal loads would be reduced to 52 and 49 percent of their present values for Lakes Erie and Ontario, respectively. Achievement of 0.5 mg P/L in final effluents for these plants would reduce municipal loads to 28 and 27 percent of present values for the two lakes.

The magnitude of municipal load reductions may be placed in perspective by comparison to other sources of phosphorus to the lower Great Lakes. The present municipal loading data are presented with data on loads from other sources of phosphorus to Lakes Erie and Ontario and combined to give total phosphorus loads to the lakes in Table 13. These data indicate that municiapl point sources account for 27 and 21 percent of the present total phosphorus load to Lakes Erie and Ontario, respectively. The effect of municipal load reductions on total phosphorus loads, as a result of all wastewater treatment plants larger than 1 mgd (3785 m^3/d) achieving 1.0 and 0.5 mg P/L in the basins of the two lakes, is illustrated in Figure 9. Effluent standards of 1.0 and 0.5 mg P/L would represent total load reductions of 13 and 19 percent, while for Lake Ontario, the same standards would represent reductions in the total phosphorus load of 11 and 15 percent.

It should be noted that the load reductions shown in Figure 9 for Lake Ontario do not account for reductions in the load from Lake Erie to Lake Ontario by way of the Niagara River. Such a load reduction would be a likely result should all wastewater plants in the Lake Erie basin achieve 1.0 or 0.5 mg P/L effluent levels. Therefore, the above Lake Ontario load reductions are minimum values and would probably be larger as a result of reductions in the relatively large phosphorus load from the Niagara River. In any event, a major conclusion derived from Figure 9 is that a 0.5 mg P/L effluent standard alone will not allow the attainment of IJC target loads of 11,000 and 7,000 metric tons/year for Lakes Erie and Ontario, respectively. The total load to Lake Erie under a 0.5 mg P/L standard would be reduced to approximately 13,670 metric tons/year. The total load to Lake Ontario would be reduced at least to 11,515 metric tons/year; however, it is unlikely that a 4000 metric ton/year reduction (70 percent) would occur in the Niagara River to bring the Lake Ontario load down to 7000 metric tons/year.

TABLE 13. PHOSPHORUS LOADING TO LAKES ERIE AND ONTARIO, IN METRIC TONS/YEAR

	Lake Erie			Lake Ontario		
	U.S.	Canada	Total	U.S.	Canada	Total
Point Sources						
Municipal[1]	4323	232	4555	1973	885	2858
Industrial[2]	211	38	249	81	120	201
Upper Lake						
Niagara River (Lake Erie)[3]	-	-	-	-	-	5613
Detroit River (Lake Huron)[3]	-	-	1080	-	-	-
Non-Point Sources						
Diffuse/Tributary[3]	6156	1804	7960	2123	1131	3254
Direct Runoff[3]	1576	740	2315	975	261	1236
Atmospheric[4]			744			438
Total	12266	2814	16934	5152	2937	13600

[1] Present loading conditions as computed from survey master list

[2] Computed from IJC - (1979).

[3] Computed from Vallentyne and Thomas (1978).

[4] Computed from Gregor and Johnson (1979).

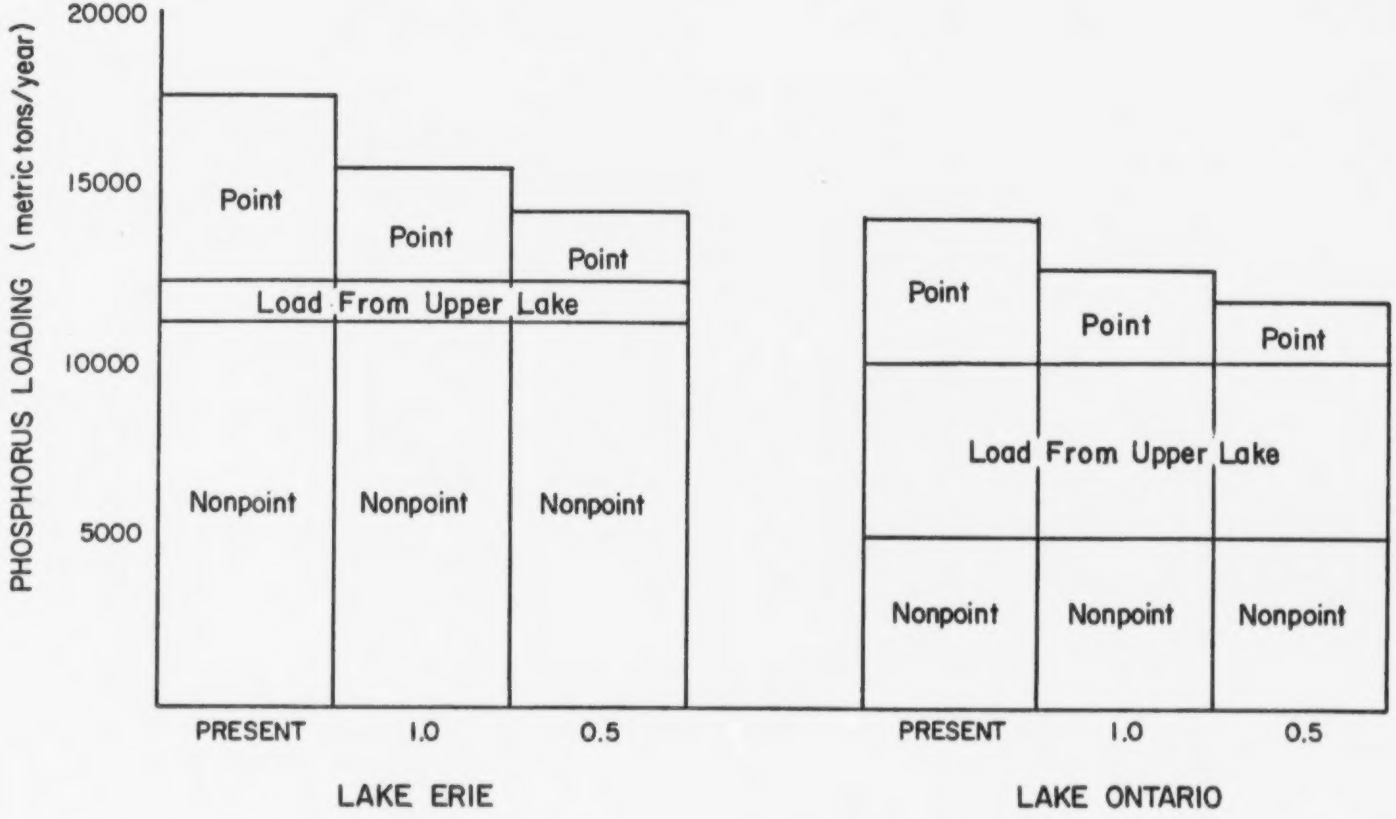

Figure 9. Comparison of point to non-point source loading of phosphorus at present conditions and at effluent limitations of 1.0 and 0.5 mg P/L for municipal point source dischargers

SECTION 6

RESULTS OF FIELD STUDIES

WASTEWATER TREATMENT PLANT DESCRIPTIONS

Given below are general descriptions of the treatment methods employed at the four wastewater plants which were studied intensively on-site during this investigation. Included in the descriptions are the approaches used for preliminary, primary, secondary, and tertiary wastewater treatment, and sludge treatment and disposal.

Gates-Chili-Ogden, 15 mgd (56775 m^3/d)

At the Gates-Chili-Ogden facility, located near Rochester, NY, raw municipal wastewater was given preliminary and primary treatment prior to biological treatment by a conventional activated sludge process. To remove phosphorus, alum was added in liquid form to the effluent of the aeration basin, upstream from the final clarifiers as illustrated in the process schematic (Figure 10). The secondary sludge, which consisted of biological and aluminum-phosphorus solids, was partially recycled to the aeration basin and partially wasted. By recycling alum with the return activated sludge, the contact period between alum and phosphorus in the wastewater was increased, which would permit kinetically-limited precipitation reactions to approach equilibrium more closely than could occur without alum recycle. Waste secondary sludge was conditioned for flotation thickening with a polymer and combined after thickening with primary sludge. The combined sludges were dewatered by vacuum filtration and incinerated or composted on-site.

Frank Van Lare, 100 mgd (378500 m^3/d)

Municipal wastewater treatment at the Frank Van Lare plant, located near Rochester, NY, consisted of two main treatment streams, as shown in the process schematic, Figure 11. Raw wastewater received preliminary screening and degritting and was then split for primary sedimentation and further treatment. To 20 percent of the total flow, liquid alum and a polymer was added just upstream from the primary clarifiers to enhance phosphorus removal during primary sedimentation. The remainder of the flow was given primary treatment, without alum addition, and biological treatment by conventional activated sludge. The clarified secondary effluent and alum-treated primary effluent were combined for chlorination prior to discharge. The primary sludges from both treatment streams were combined with wasted biological sludge for treatment by gravity thickening, vacuum filtration, and incineration.

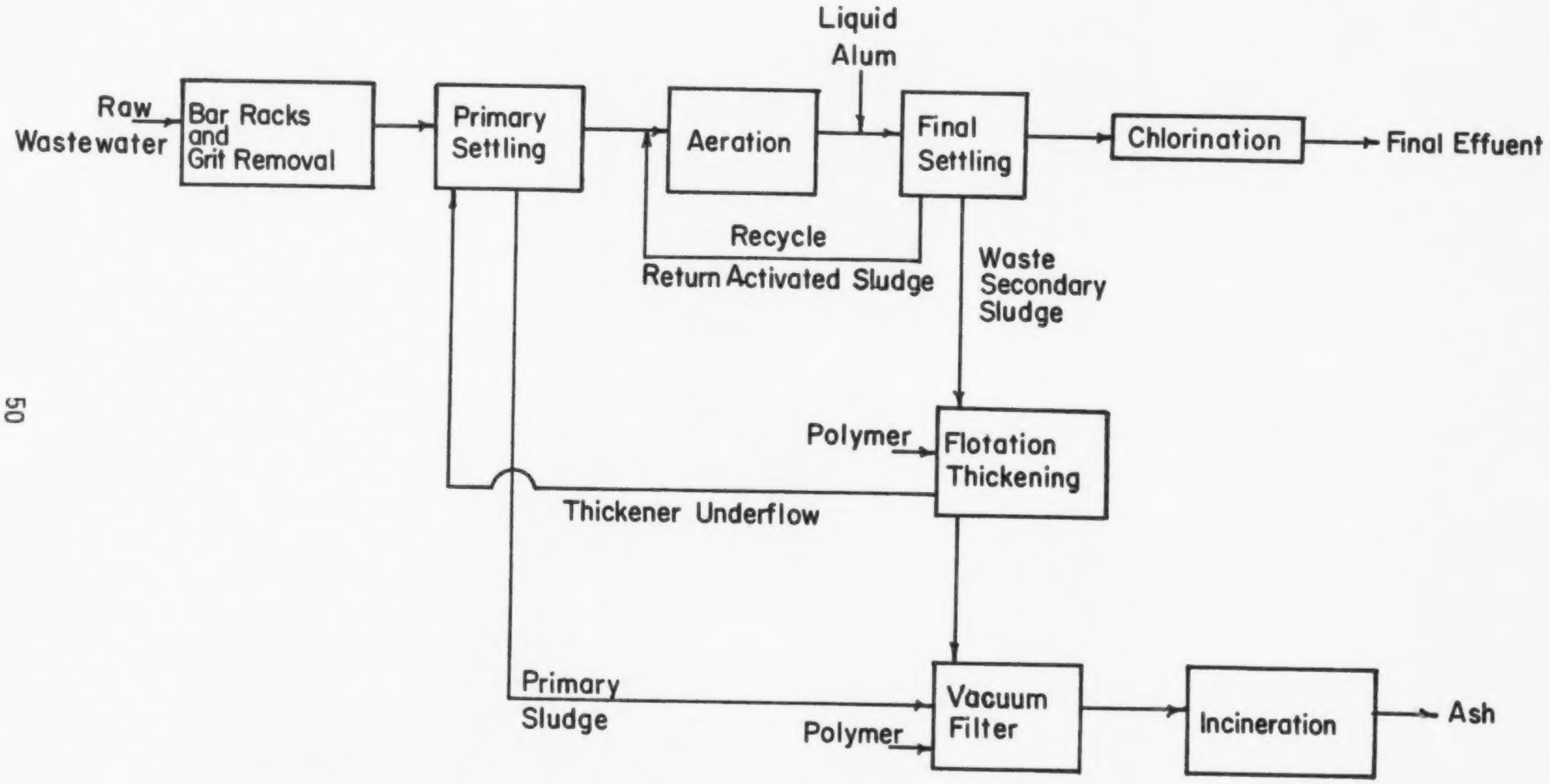

Figure 10. Process schematic for Gates-Chili-Ogden plant, NY

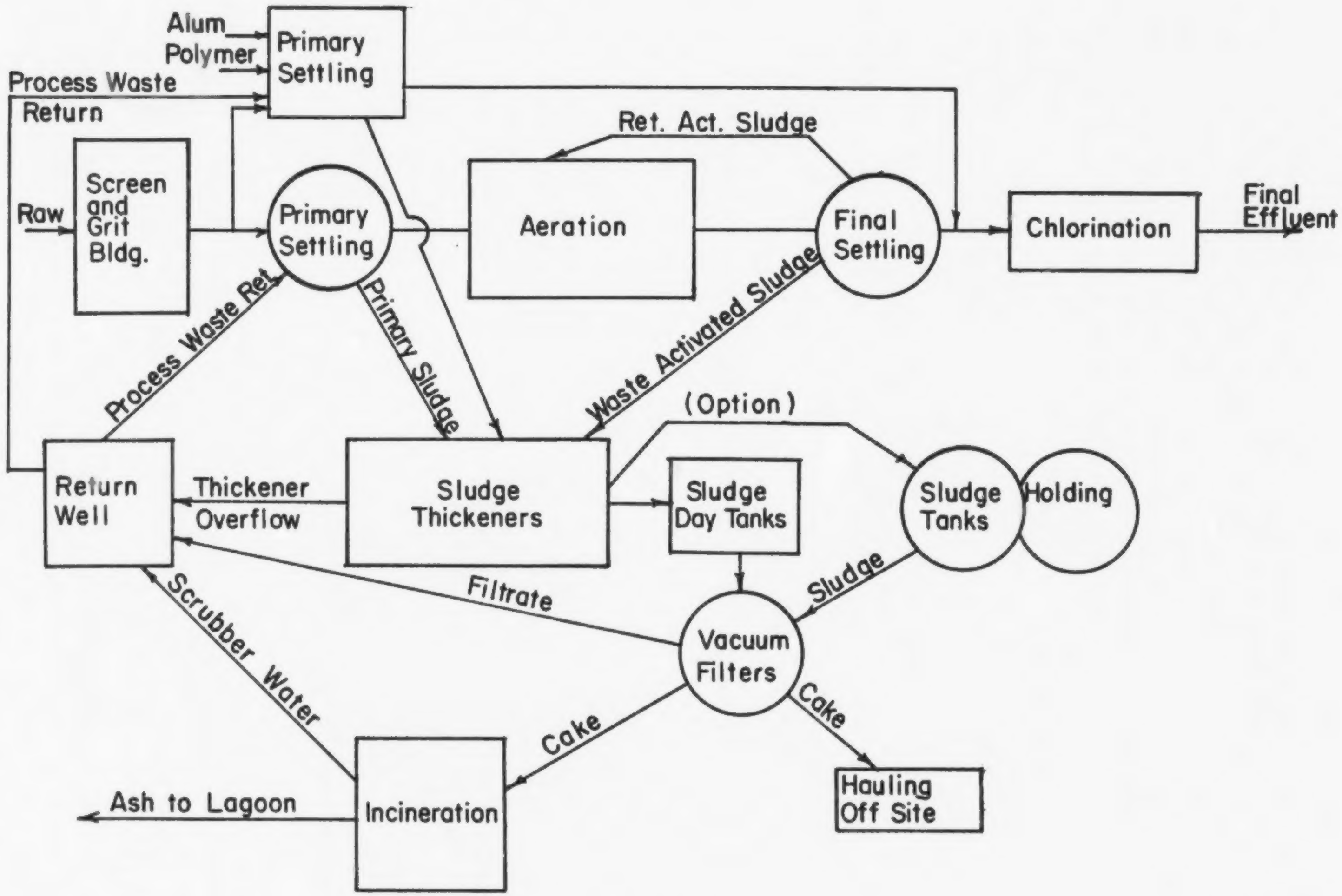

Figure 11. Process schematic for Frank Van Lare plant, NY

Big Sister Creek, 3 mgd (11355 m3/d)

The Big Sister Creek wastewater treatment plant, located near Angola, NY, was upgraded in 1978 from a primary treatment facility to a tertiary treatment system. As shown in the process schematic for the Big Sister Creek plant, Figure 12, screened and degritted raw wastewater was sent without primary sedimentation to an aeration basin for biological treatment by an extended aeration activated sludge process. Effluent from the aeration basin is clarified by sedimentation and then dosed with ferric chloride and a polymer for phosphorus removal in a solids contact clarifier. Effluent from the solids contact clarifier is applied to a sand filter after which the filtrate is chlorinated for discharge. A portion of the iron-phosphorus sludge from the solids contact clarifier is recycled back to the clarifier influent. The sludge recycle provides an increased contact period between iron and wastewater phosphorus, which permits a closer approach to precipitation equilibria, than would occur in the absence of solids recycle. Both secondary and iron-phosphorus sludges were thickened by flotation and combined for storage in an aerobic digester. Centrifugation and sand bed drying were employed for sludge dewatering. Dewatered sludge was trucked to an adjacent land fill for disposal.

Ely, 1 mgd (3785 m^3/d)

As illustrated in the process schematic for the Ely, MN wastewater treatment plant, Figure 13, screened and degritted raw wastewater was given primary settling before biological treatment, which consisted of a single-stage trickling filter. Liquid alum and a polymer were added to the trickling filter effluent to enhance phosphorus removal during secondary clarification. All biological solids and alum-phosphate sludge which collected in the final clarifiers was recycled to the influent of the primary sedimentation tanks, which served to increase the time of contact between the alum, wastewater solids, and phosphorus. The secondary effluent was chlorinated, held briefly in non-functional solids contact tanks, and passed through a dual media filter prior to discharge from the plant. Sludge from the primary clarifier was thickened by gravity and conditioned with lime prior to vacuum filtration. A landfill was used for disposal of the vacuum filter cake.

TREATMENT PLANT MONITORING

The performance of the four wastewater plants was determined by repeated sampling at fixed points along the treatment stream at each plant and characterizing the progress of treatment at each selected point. Presented in Table 14 is a listing of the sampling locations which were selected at each wastewater plant. A brief description of each location is included to specify the exact sampling point.

Though several treatment parameters were determined on the samples taken from each sampling location, special focus was given to the analysis of phosphorus and various fractions of phosphorus through the treatment plants. Additionally, a subset of samples from each plant was analyzed for selected heavy metal and organic priority pollutants, in order to assess the

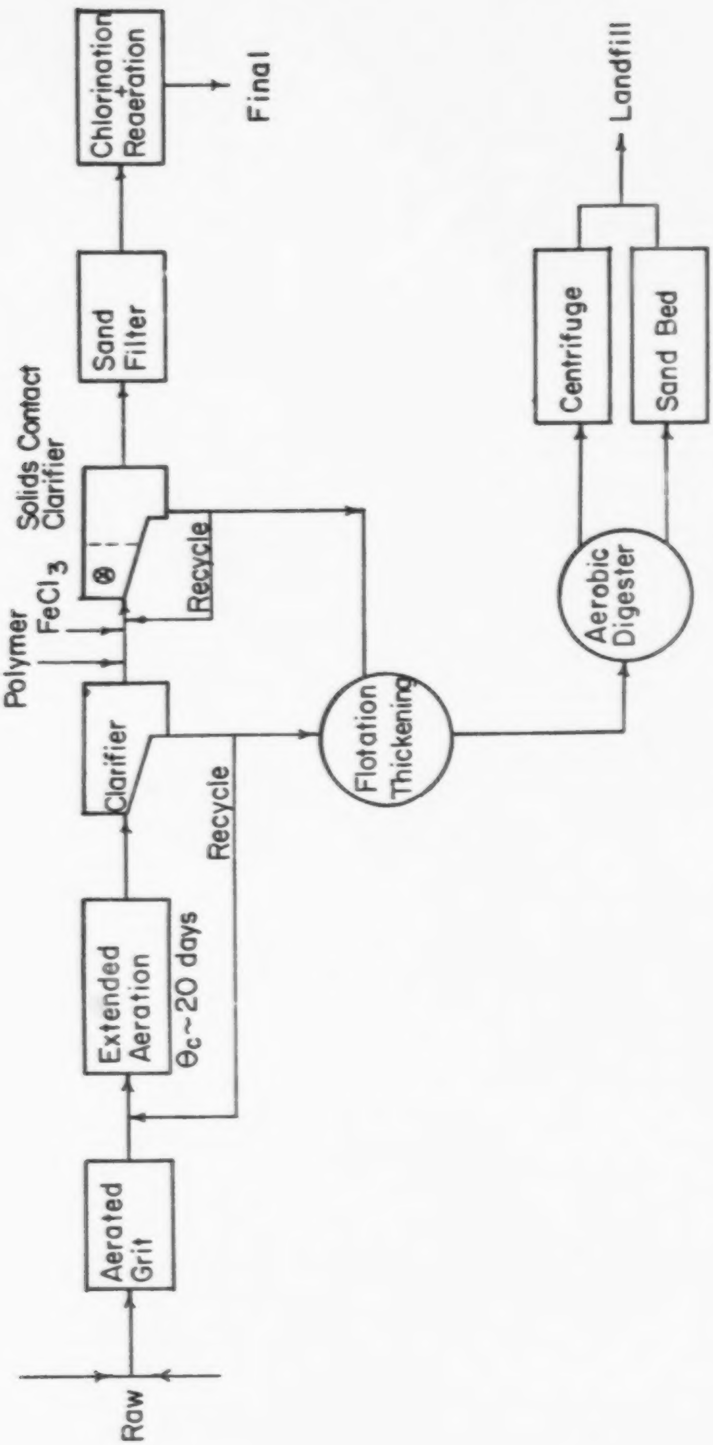

Figure 12. Process schematic for Big Sister Creek plant, NY

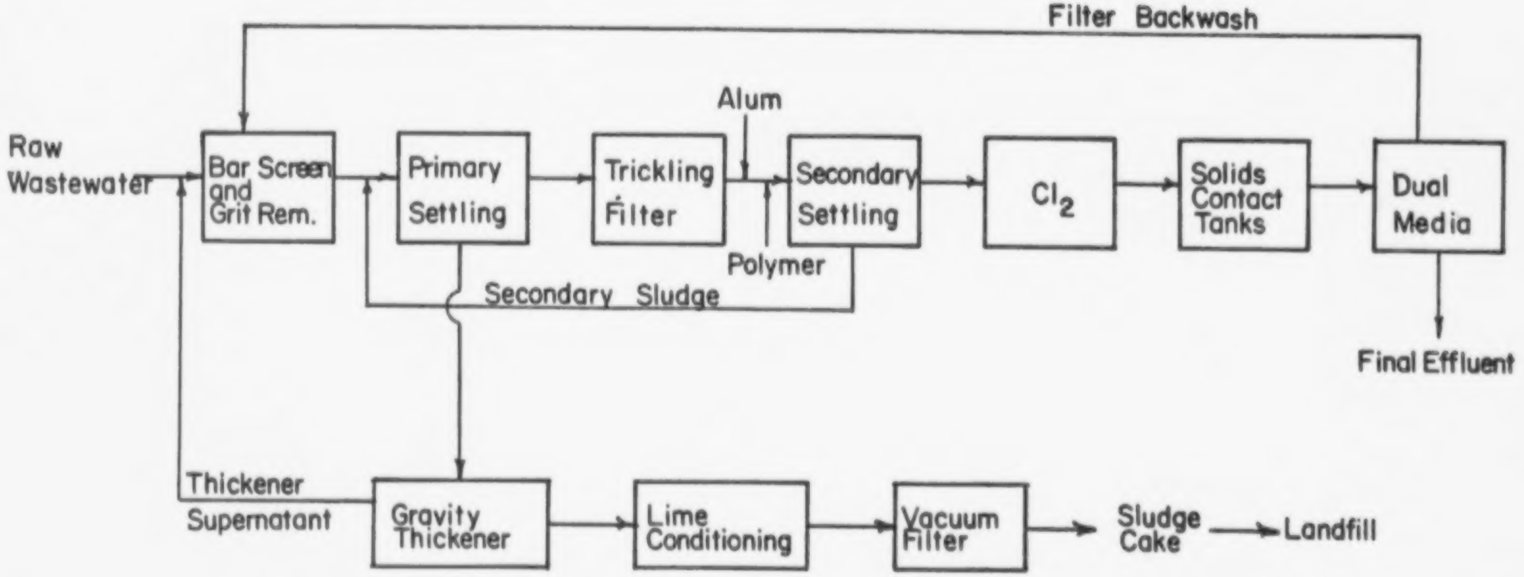

Figure 13. Process schematic for Ely plant, MN

TABLE 14. SAMPLING LOCATIONS WITHIN MONITORED TREATMENT PLANTS

Plant Name	Sampling Location Name	Location Characteristics
Gates-Chili-Ogden	Raw Influent	Sample taken from aerated grit chamber
	Primary Effluent	Sample taken from weir of primary clarifier
	Secondary Effluent	Sample taken from weir of final clarifier
Frank Van Lare	Raw Influent	Sample taken from aerated grit chamber
	Alum Effluent	Sample taken from weir of primary clarifier after alum treatment
	Biological Effluent	Sample taken from weir of final clarifier
Big Sister Creek	Raw Influent	Sample taken from post-screening wet well
	Secondary Effluent	Sample taken from weir of secondary clarifier
	Filtered Effluent	Sample taken from sand filter effluent channel
Ely	Raw Effluent	Sample taken from aerated grit chamber
	Secondary Effluent	Sample taken from weir of secondary clarifier
	Filtered Effluent	Sample taken from dual media filter effluent channel

effectiveness of the differing treatment methods of the wastewater plants on such pollutants.

Overall Treatment Performance

Presented in Table 15 is a summary of data collected at the four treatment plants on biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solids (SS), total phosphorus (Total P), total Kjeldahl nitrogen (TKN), and total nitrogen (Total N), the latter of which was estimated from the sum of TKN and nitrate plus nitrite nitrogen. A complete listing of the data summarized in Table 15 is given in Appendix C. Also given in Table 15 are figures for overall percent removals of the listed parameters for each wastewater plant.

At the Gates-Chili-Ogden plant sampling focused on the raw influent and final effluent. Data on three samples of primary effluent are included in Appendix C. The data in Table 15 demonstrate removal percentages on the order of 90 percent for conventional treatment parameters including Total P, during the periods of sampling, and indicate a well designed and operated wastewater plant.

The Frank Van Lare plant, during the monitoring period for this investigation, was less efficient than the other plants at removing common wastewater pollutants, as indicated by the data in Table 15. Removal of BOD_5 and COD through the biological treatment stream averaged over 80 percent, while through the primary by-pass stream, removal of the two pollutants averaged 29 and 47 percent, respectively. Removal of total P and suspended solids appeared equally effective through either biological or primary + alum treatment, with approximately 60 and 70 percent removal of the two pollutants by either method. The effectiveness of the Frank Van Lare plant for pollutant removal is indicated by the overall percentages given in Table 15. The overall percentage removals were calculated on the basis of an 80/20 percent split of the raw influent between biological and primary + alum treatment.

Performance data for the Big Sister Creek wastewater plant, Table 15, show excellent treatment efficiency for BOD, COD, and suspended solids, with greater than 93 percent reductions in each pollutant through the plant. Additionally, the total N concentration was reduced by nearly 60 percent through the plant and the final effluent total N was predominately nitrate (approximately 97 percent), an expected benefit of the extended aeration process. The total P content of the wastewater was reduced by an average of 86 percent during treatment, though at intermediate stages of treatment the removal of total P was significantly greater than this figure. A more detailed assessment of phosphorus removal performance will be given in the next section.

As the data in Table 15 indicate, the Ely wastewater treatment plant performed well for removal of BOD, total P, and suspended solids, each of which was reduced by greater than 85 percent during treatment. Removal of COD was less effective at 75 percent, than removal of BOD, and the final effluent from the plant was not nitrified with approximately 63 percent of

TABLE 15. PERFORMANCE OF FOUR WASTETREATMENT PLANTS

	Treatment Performance Parameters*					
Plant Name and Sampling Locations	BOD_5 (mgO_2/L)	COD (mgO_2/L)	SS (mg/L)	Total P (mg/L)	TKN (mgN/L)	Total N** (mgN/L)
Gates-Chili-Ogden						
Raw Influent	187±14(3)	385±74(12)	165±54(12)	6.3±1.5(12)	24.8±5.2(6)	
	(170-195)	(278-532)	(112-295)	(3.8-8.6)	(16.2-29.6)	
Primary Effluent	-	290±37(3)	69±8(3)	5.5±0(3)	25.2±3.5(2)	
	-	(248-319)	(61-76)	(5.0-6.1)	(22.7-27.6)	
Secondary Effluent	16±1(3)	50±18(12)	9±3(12)	0.8±0.3(12)	4.0±1.8	
	(15-17)	(34-103)	(7-13)	(0.3-1.4)	(1.7-5.9)	
% Removal (Overall)	91	87	94	88	84	
Frank Van Lare						
Raw Influent	212±52(10)	448±117(10)	186±102(10)	3.8±1.2(10)	20.0±4.3(5)	
	(149-295)	(337-735)	(127-470)	(2.8-6.9)	(16.9-27.5)	
Alum Effluent	151±27(10)	238±37(10)	53±14(10)	1.3±0.4(10)	13.9±1.3(5)	
	(103-196)	(179-286)	(32.0-76)	(0.8-2.0)	(12.1-15.0)	
% Removal (Alum)	29	47	72	66	30	
Biological Effluent	30±19(10)	88±32(10)	53±32(10)	1.5±0.9(10)	4.4±2.3(5)	
	(9-65)	(49-141)	(17-119)	(0.5-3.1)	(2.1-7.6)	
% Removal (Biological)	86	80	72	60	78	
% Removal (Overall)	74	74	72	61	68	
Big Sister Creek						
Raw Influent	130±4(2)	446±215(13)	264±156(13)	6.8±2.3(13)	31.7±10.7(6)	31.7±10.7(6)
	(127-133)	(228-1062)	(111-670)	(4.01-10.2)	(21.8-44.9)	-
Secondary Effluent	4±0(2)	46±9(13)	8±2(13)	2.3±0.2(13)	0.9±0.1(6)	14.7±1.8(6)
	(3-4)	(28-58)	(5-12)	(1.8-2.6)	(0.8-1.1)	-
Filtered Effluent	2±0(2)	29±6(13)	2±1(13)	0.9±0.1(13)	0.4±0.1(5)	13.9±3.5(6)
	(2)	(17-38)	(1-4)	(0.7-1.1)	(0.4-0.5)	-
% Removal (Overall)	98	93	99	86	99	56

(continued)

TABLE 15 (continued)

Plant Name and Sampling Locations	Treatment Performance Parameters*					
	BOD_5 (mgO_2/L)	COD (mgO_2/L)	SS (mg/L)	Total P (mg/L)	TKN (mgN/L)	Total N** (mgN/L)
Ely						
Raw Influent	181±120(2) (96-266)	270±86(12) (147-416)	123±42(12) (64-212)	3.8±1.3(12) (2.2-7.0)	19.0±8.4(5) (10.2-32.8)	19.1±8.4(5) -
Secondary Effluent	35±3(2) (33-37)	119±23(12) (79-154)	58±9(12) (42-68)	1.7±0.5(12) (1.0-2.6)	14.6±0.5(5) (14.0-14.9)	15.0±0.5(5) -
Filtered Effluent	15±2(2) (13-16)	68±12(12) (53-94)	13±3(12) (8-19)	0.6±0.2(12) (0.3-0.9)	12.0±.0(5) (10.9-13.2)	13.7±1.1(5) -
% Removal (Overall)	92	75	89	85	37	28

* Format of data: mean ± standard deviation (number of samples) (range of values observed)

** Total N = (TKN) + (NO_3-N) + (NO_2-N) the influent TKN remaining.

Phosphorus Removal

Presented in Table 16 is a summary of the data collected on phosphorus during the investigation. A more detailed presentation of phosphorus data may be found in Appendix C. Given in Table 16 is a listing, by plant and sampling locations within each plant, of the average total phosphorus concentration and concentration of several fractions of the total phosphorus in the wastewater. Statistical distribution parameters for each group of samples are given, also.

Gates-Chili-Ogden--

Removal of phosphorus at the Gates-Chili-Ogden plant is illustrated in Figure 14, which gives the concentrations of total phosphorus and several fractions of particulate and soluble phosphorus in the raw wastewater and in the final effluent before chlorination. As the data in Figure 14 indicate, addition of alum to the biological effluent before secondary clarification, as practiced at the Gates-Chili-Ogden plant, resulted in a reduction in the concentration of all the fractions of phosphorus for which samples of final effluent were analyzed. However, the relative amount of particulate phosphorus increased during treatment, as shown in Figure 15. This change in the relative distribution of the phosphorus fractions illustrates that soluble phosphorus was removed more efficiently (greater than 90 percent removal) than particulate phosphorus (approximately 80 percent removal), by the treatment approach employed at the Gates-Chili-Ogden plant. In addition to the increased level of particulate phosphorus, as a fraction of the total phosphorus which remained after treatment, an increase was noted in the relative contribution of NaOH extractable phosphorus to the total particulate phosphorus which remained, as shown in Figure 15.

Frank Van Lare--

Removal of phosphorus at the Frank Van Lare wastewater plant is illustrated in Figure 16, which shows concentrations of total phosphorus and phosphorus fractions in the raw wastewater, the alum-treated effluent, and the biologically-treated effluent. It is apparent from the data that biological and physical-chemical treatment with alum were nearly equal in reducing the total phosphorus content of the wastewater during the sampling periods of this investigation. The figures given in Table 16 indicate that both biological and physical-chemical treatment reduced the total phosphorus content of the wastewater by similar amounts , 60 and 66 percent, respectively. Additionally, both treatment streams were more effective at reducing the soluble phosphorus fraction than that of particulate phosphorus. Approximately 70 percent of the total soluble phosphorus of the raw influent was removed through the biological treatment stream while nearly 90 percent of that fraction was removed during alum treatment. Thus, alum was more effective than biological treatment for reducing the soluble phosphorus of the wastewater. Particulate phosphorus removal was similar through the two treatment streams and averaged approximately 50 percent of the raw wastewater particulate phosphorus. The levels of total NaOH extractable

TABLE 16. CONCENTRATION OF PHOSPHORUS FRACTIONS AND REMOVAL PERCENTAGES THROUGH FOUR WASTEWATER PLANTS

Plant Name and Sampling Locations*	Phosphorus Concentration, mg P/L**				
		Phosphorus Fractions			
		Particulate (PP)		Soluble (SP)	
	Total P	Total PP	Total NaOH-PP	Total SP	SRP
Gates-Chili-Ogden					
Raw Influent (12)	6.28±1.50 (3.82-8.64)	2.17±0.72 (1.08-3.66)	1.70±0.55 (0.92-3.02)	3.89±1.13 (2.46-6.46)	2.54±0.54 (1.50-3.34)
Primary Effluent (3)	5.47±0.56 (4.98-6.08)	1.52±0.03 (1.47-1.56)	- -	4.00±0.36 (3.60-4.28)	2.53±0.54 (1.92-2.94)
Secondary Effluent (12)	0.75±0.34 (0.32-1.36)	0.42±0.15 (0.21-0.76)	0.37±0.10 (0.22-0.61)	0.34±0.20 (0.14-0.74)	0.19±0.12 (0.10-0.42)
% Removal (Overall)	88	81	78	91	92
Frank Van Lare					
Raw Influent (10)	3.81±1.18 (2.85-6.90)	2.28±0.81 (1.53-4.15)	1.87±0.56 (1.44-3.13)	1.14±0.45 (0.42-2.01)	0.86±0.44 (0.18-1.75)
Alum Effluent (10)	1.31±0.39 (0.79-2.04)	1.06±0.36 (0.59-1.76)	0.96±0.31 (0.65-1.56)	0.11±0.05 (0.03-0.17)	0.03±0.04 (0.00-0.14)
% Removal (Alum)	66	54	49	90	96
Biological Effluent (10)	152±0.93 (0.49-3.06)	1.14±0.78 (0.37-2.78)	0.90±0.59 (0.30-2.06)	0.34±0.26 (0.09-0.63)	0.27±0.31 (0.01-0.85)
% Removal (Biological)	60	50	52	70	69
% Removal (Overall)	61	51	51	74	74
Big Sister Creek					
Raw Influent (13)	6.81±2.34 (3.98-11.07)	4.40±2.74 (1.81-11.84)	3.71±87 (1.28-7.34)	2.15±0.52 (1.43-3.27)	1.43±0.52 (0.75-2.47)
Secondary Effluent (13)	2.72±0.25 (1.83-2.65)	0.17±0.04 (0.12-0.25)	0.15±0.03 (0.11-0.24)	2.13±0.24 (1.75-2.53)	1.81±0.32 (1.32-2.28)
Solids Contact (4)	0.35±0.03 (0.32-0.39)	0.19±0.04 (0.14-0.23)	0.18±0.95 (0.12-0.23)	0.16±0.03 (0.13-0.19)	0.08±0.03 (0.06-0.12)

(continued)

TABLE 16 (continued)

Plant Name and Sampling Locations*	Phosphorus Concentration, mg P/L**				
		Phosphorus Fractions			
		Particulate (PP)		Soluble (SP)	
	Total P	Total PP	Total NaOH-PP	Total Sp	SRP
Filtered Effluent (13)	0.94±0.14 (0.68-1.12)	0.06±0.04 (0.02-0.13)	0.05±0.03 (0.02-0.13)	0.89±0.12 (0.65-1.07)	0.75±0.14 (0.50-0.92)
% Removal (Solids Contact)	95	96	95	93	94
% Removal (Overall)	86	99	99	59	48
Ely					
Raw Influent (2)	3.77±1.29 (2.20-6.97)	2.42±0.85 (1.52-4.78)	1.82±0.94 (0.96-4.56)	1.43±0.64 (0.37-2.72)	0.99±0.38 (0.30-1.61)
Secondary Effluent	1.72±0.45 (1.02-2.55)	1.62±0.41 (0.93-2.30)	1.40±0.36 (0.86-1.94)	0.03±0.01 (0.02-0.06)	0.01±0.01 (0.00-0.02)
Filtered Effluent (12)	0.56±0.19 (0.34-0.92)	0.49±0.17 (0.30-0.78)	0.47±0.17 (0.25-0.75)	0.04±0.02 (0.02-0.09)	0.01±0.01 (0.00-0.03)
% Removal (Overall)	85	80	74	97	99

* Number in parantheses signifies number of samples analyzed.

** Format of data: mean concentration ± standard deviation (range of concentrations observed)

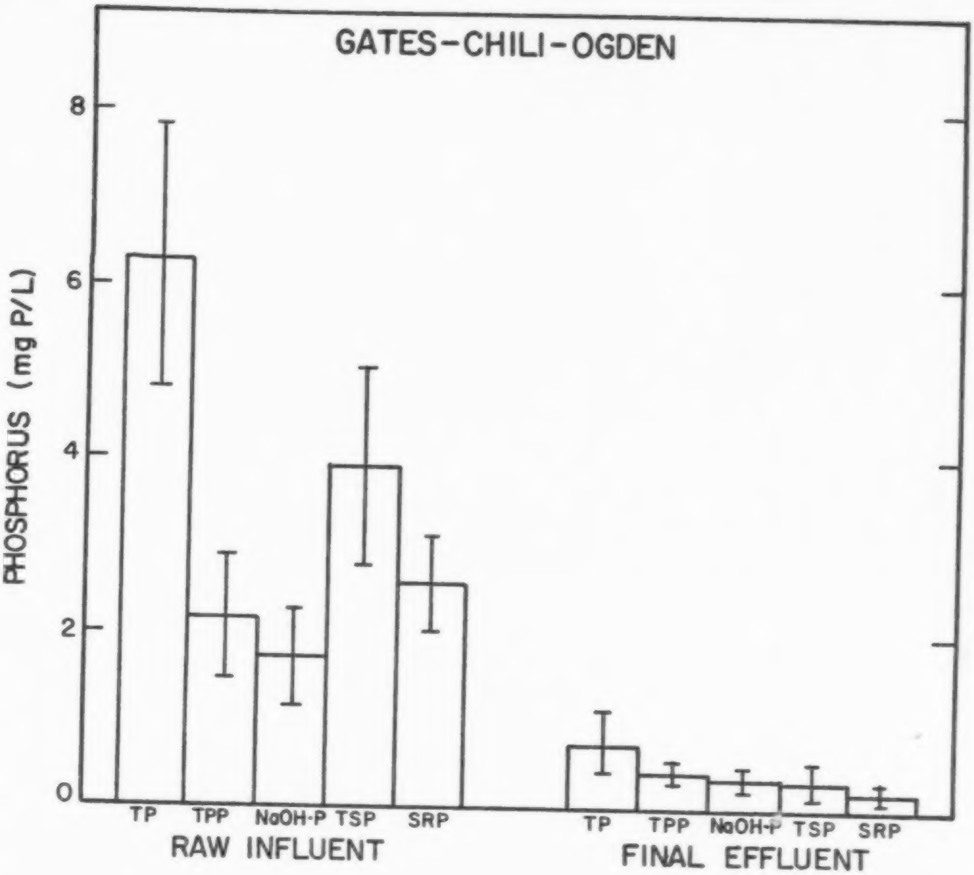

Figure 14. Mean concentrations of total phosphorus and phosphorus fractions at the Gates-Chili-Ogden plant

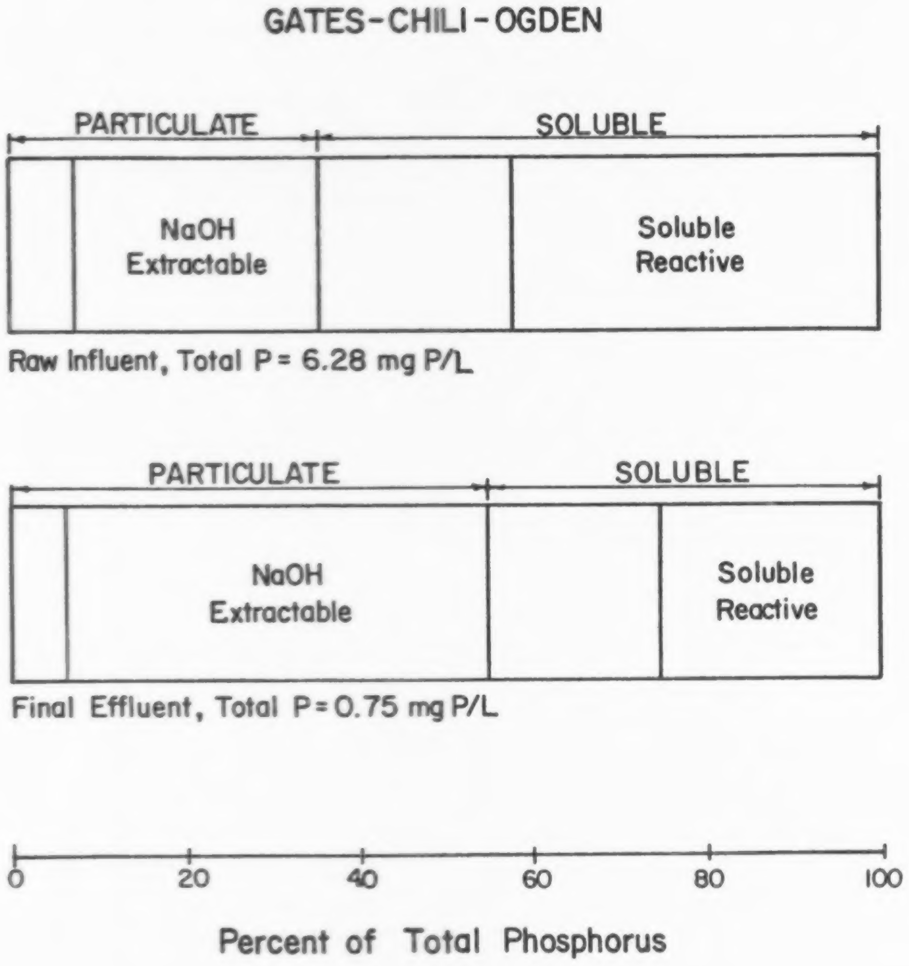

Figure 15. Distribution of phosphorus fractions at the Gates-Chili-Ogden plant

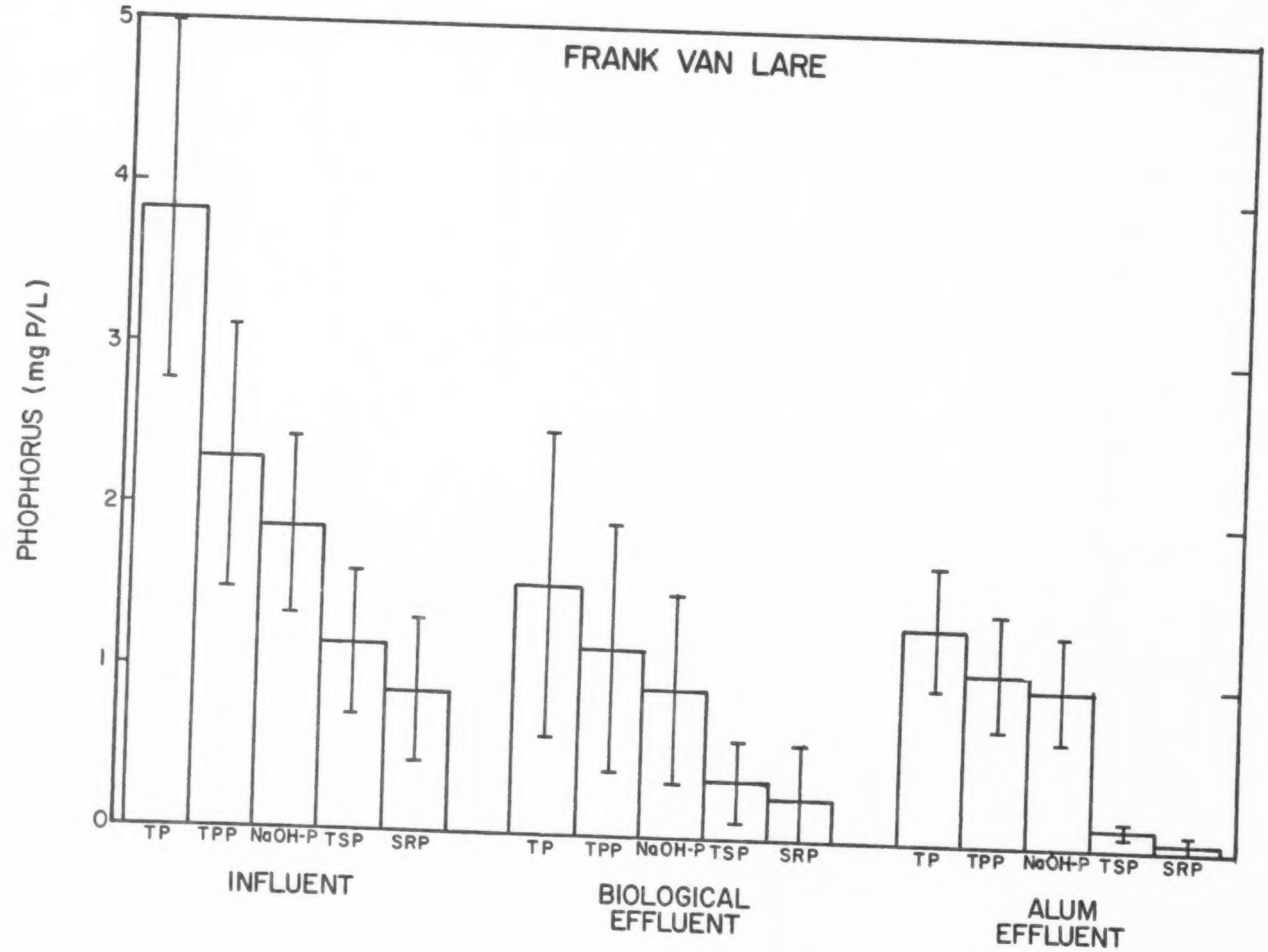

Figure 16. Mean concentrations of total phosphorus and phosphorus fractions at the Frank Van Lare plant

particulate phosphorus followed closely those of total particulate phosphorus in both treatment systems.

As indicated previously, soluble phosphorus was removed more effectively than particulate phosphorus in the Frank Van Lare plant. The differential removal of these two fractions resulted in the phosphorus fraction distributions shown in Figure 17 for the raw influent, alum and biological effluents at the Van Lare wastewater plant. It is apparent from Figure 16 that particulate phosphorus, predominantly the total NaOH extractable fraction, was the main component of the phosphorus which remained in the treated wastewater, whether treatment was given through the biological or alum-treated stream. Moreover, a greater portion of the total particulate phosphorus which remained after alum treatment could be extracted with NaOH, as compared to the particulate phosphorus in the biological effluent.

Big Sister Creek--

The performance of the Big Sister Creek wastewater plant for removal of phosphorus is presented in Table 16 and illustrated in Figure 18 for fixed sampling points along the treatment stream. Figure 18 shows a large reduction in total raw wastewater phosphorus from biological treatment alone, due almost exclusively to removal of particulate phosphorus. The effluent from the secondary clarifier averaged 0.17 mg P/L of total particulate phosphorus, compared with 4.40 mg P/L in the raw wastewater, while the total soluble phosphorus concentration averaged 2.13 and 2.15 mg P/L on samples taken from the two locations. The effectiveness of iron for further phosphorus removal can be seen from the data in Figure 18 for the phosphorus in the effluent of the solids contact clarifier. The data indicate that iron precipitation reduced the total soluble phosphorus from 2.13 mg P/L in the secondary effluent, to 0.16 mg P/L, a reduction of 92 percent. The increased concentration of phosphorus observed in the filtered effluent, after iron precipitation, was due to routing of a portion of the secondary effluent around the solids contact clarifier for mixing with the iron treated effluent downstream from the clarifier and application to the sand filters.

As illustrated in Figure 19 the distribution of the phosphorus fractions relative to the total phosphorus changes dramatically during treatment. In the raw wastewater, particulate phosphorus, predominately extractable by NaOH, represented nearly 65 percent of the total phosphorus, while the remaining soluble phosphorus was principally soluble reactive phosphorus. However, after biological treatment and clarification, the particulate phosphorus fraction was reduced greatly, and soluble reactive phosphorus comprised approximately 80 percent of the total phosphorus which remained. After iron treatment, the low concentration of phosphorus which remained occurred mainly as NaOH extractable particulate and soluble reactive phosphorus. Finally, as the flows were recombined and sent to the sand filters, the filtered effluent contained phosphorus fractions which were similar to the clarified biological effluent, with soluble reactive phosphorus as the main component.

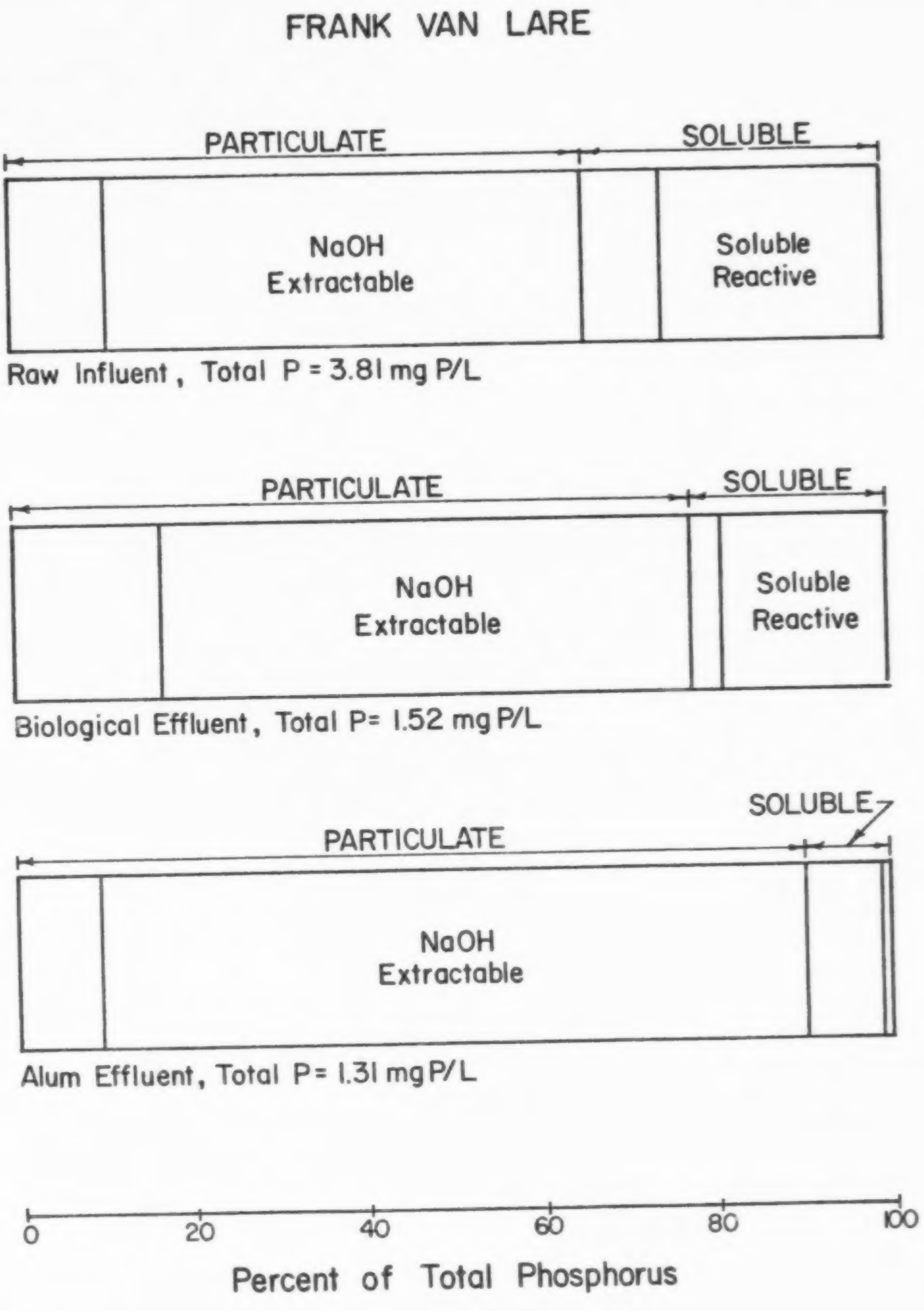

Figure 17. Distribution of phosphorus fractions at the Frank Van Lare plant

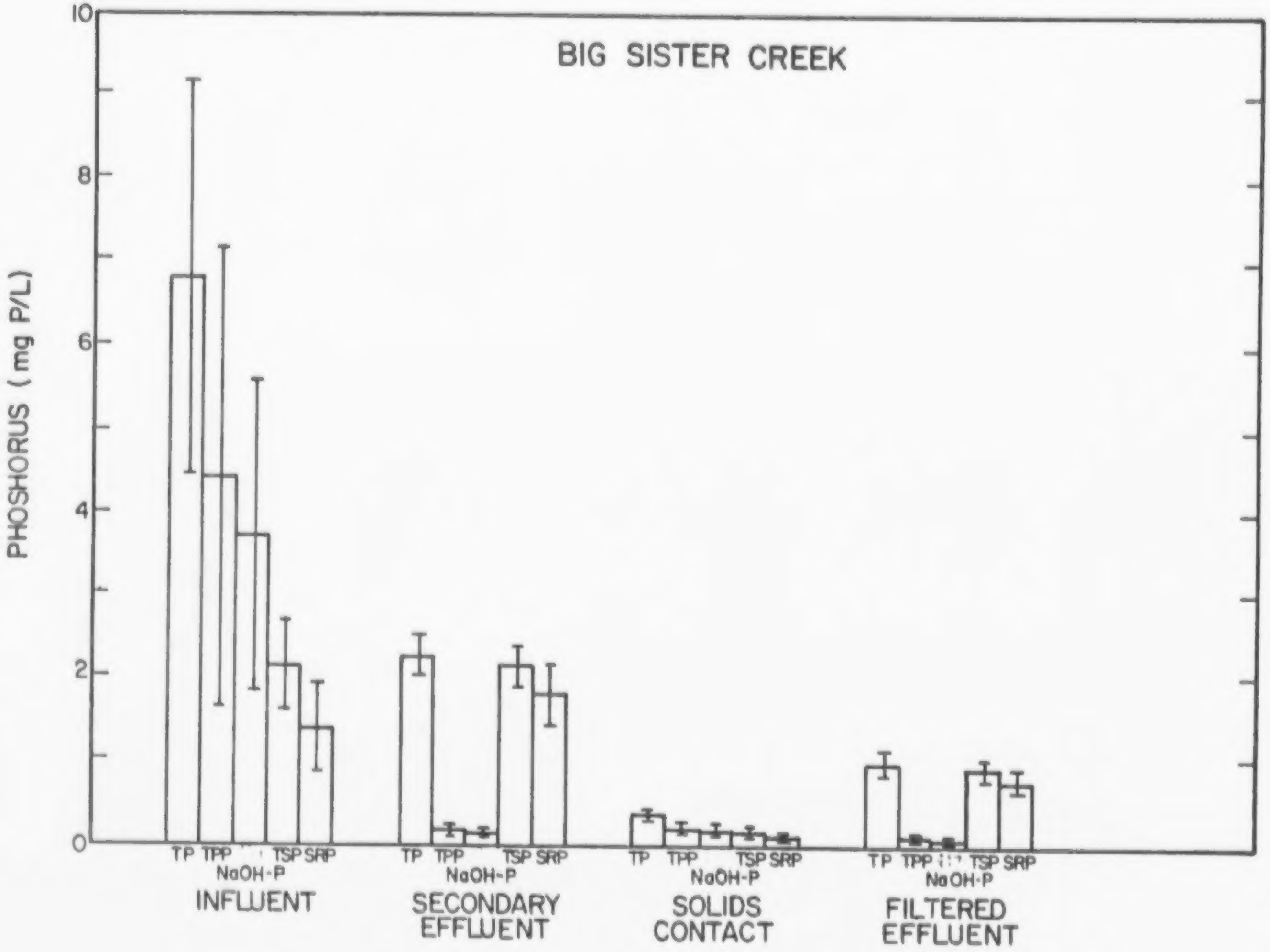

Figure 18. Mean concentrations total of phosphorus and phosphorus fractions at the Big Sister Creek plant

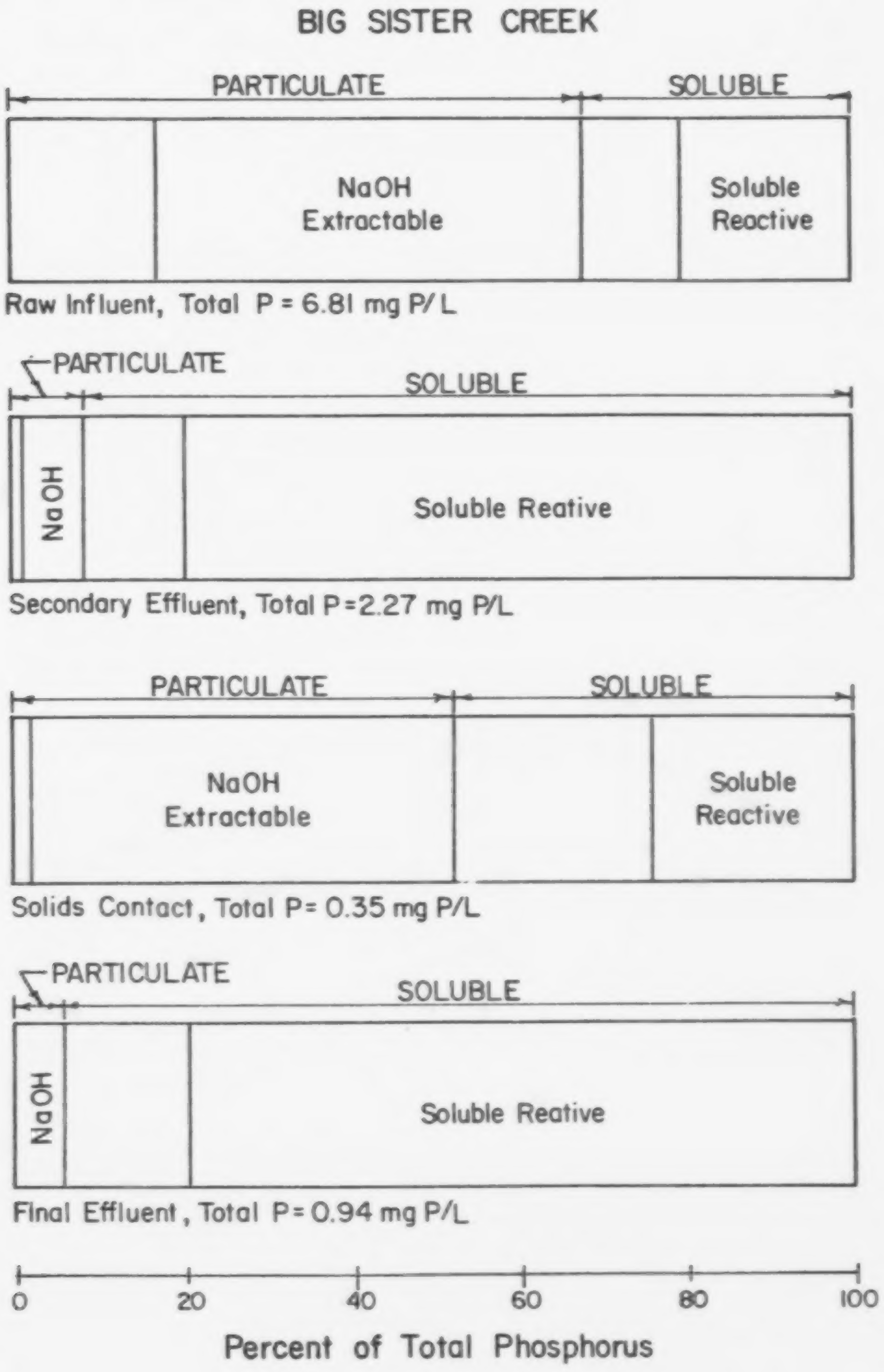

Figure 19. Distribution of phosphorus fractions at the Big Sister Creek plant

Ely--

Data on phosphorus removal through the Ely wastewater treatment plant are presented in Table 16 and illustrated in Figure 20. Figure 20 indicates significant reduction of total wastewater phosphorus occurred both as a result of alum addition to the trickling filter effluent, and as a result of dual media filtration. As Figure 20 illustrates, alum precipitation was much more efficient at reducing the soluble rather than the particulate fraction of the total raw wastewater phosphorus. Removal of the total particulate fraction averaged 33 percent from the raw influent to the clarified, alum-treated biological effluent, compared to 98 percent removal for the total soluble fraction. Through the dual media filter, the extremly low concentrations of soluble phosphorus did not change, while the total particulate fraction was reduced to 20 percent of the raw wastewater particulate phosphorus.

An examination of the distribution of fractions of total phosphorus through the plant shows the approach to treatment at Ely favored removal of phosphorus from the soluble fraction to the extent that over 90 percent of the total phosphorus which remained in the wastewater after alum treatment or filtration occurred as particulate phosphorus (Figure 21). Additionally, the NaOH extractable fraction of the total particulate phosphorus was an increasingly predominant component of that fraction, relative to the total phosphorus that remained in the wastewater at the stages of treatment which were sampled.

Priority Pollutants

During the investigation infrequent samples were taken from the locations given in Table 14 for analysis of the priority pollutants: nickel, zinc, cadmium, total polychlorinated biphenyl (PCB), and total chlorinated hydrocarbon pesticides (CHP). The results of these analyses are presented in Table 17. These determinations were made to gauge the possibility that removal techniques for control of phosphorus to defined levels might offer side benefits of enhanced removal of other pollutants.

Toxic Heavy Metals--

No trend was noted to suggest removal of nickel or cadmium through the four treatment plants which were monitored. However, as indicated by the data in Table 17, reductions in total zinc concentrations from the levels found in the raw influent samples were noted at all four plants, and the lowest concentrations of total zinc were found in samples taken from filtered effluents.

Organic Pollutants--

None of the samples which were analyzed for organic pollutants contained measurable concentrations of PCB. However, samples from three of the four plants contained quantifiable levels of CHP. The pesticide, p-p-DDT, was determined at 0.2 μg/L in the raw influent to the Gates-Chili-Ogden plant. Additionally, aldrin was found at 0.09 μg/L in the filtered effluent from

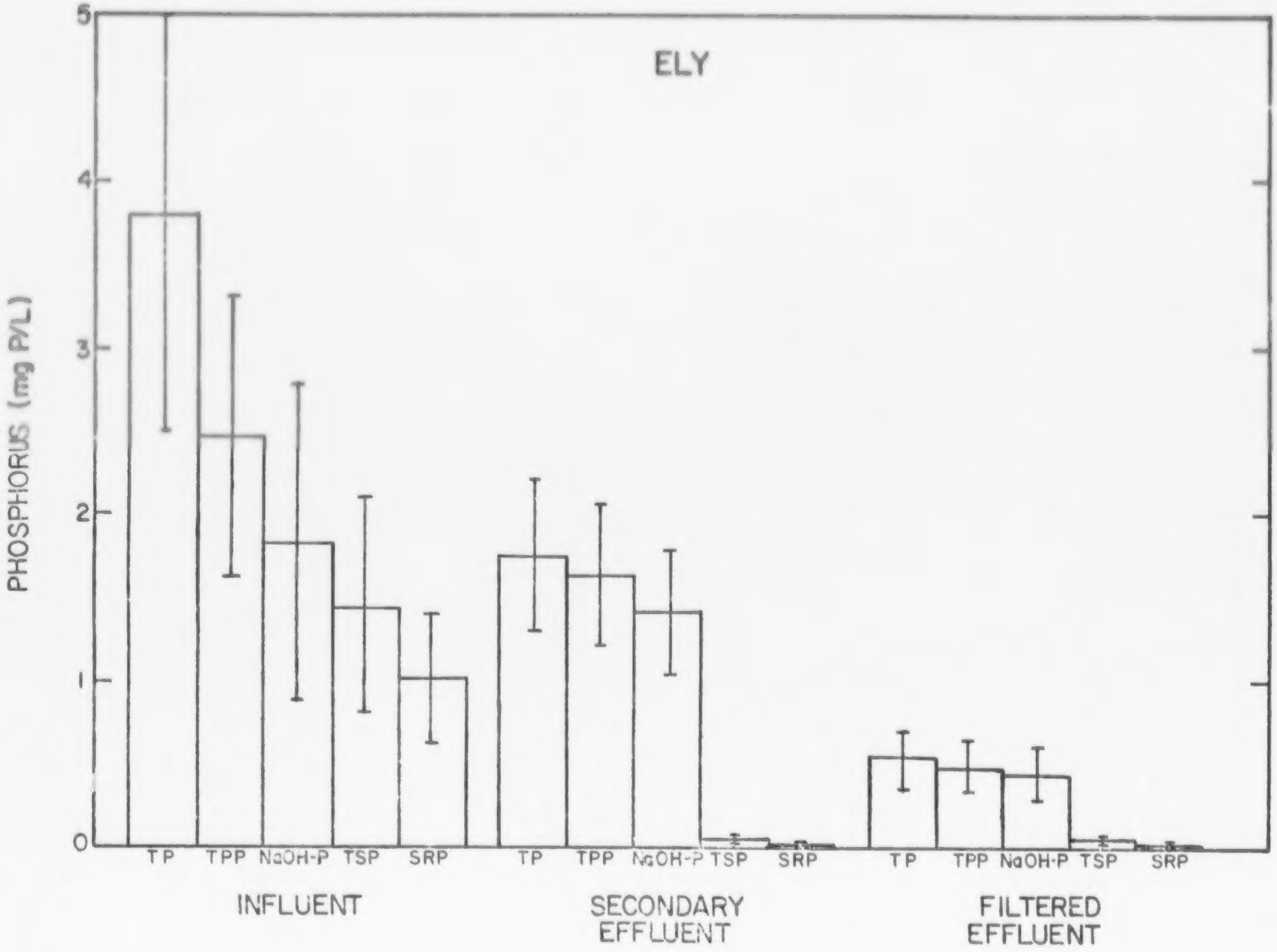

Figure 20. Mean concentrations total of phosphorus and phosphorus fractions at the Ely plant

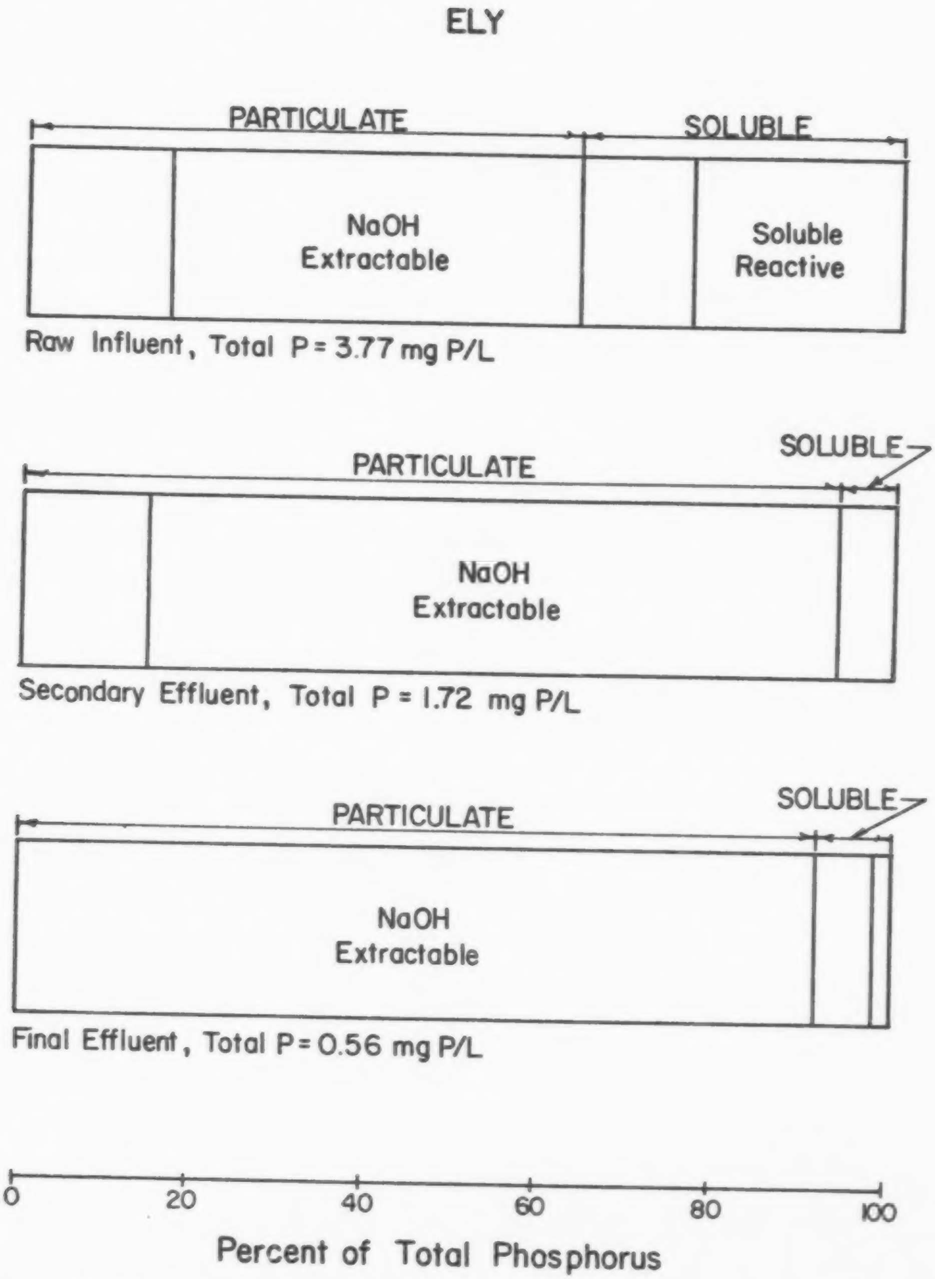

Figure 21. Distribution of phosphorus fractions at the Ely plant

TABLE 17. CONCENTRATIONS OF PRIORITY POLLUTANTS IN WASTEWATER SAMPLES FROM MONITORED TREATMENT PLANTS

Plant Name and Sampling Location	Heavy Metals*			Organics**	
	Ni (mg/L)	Zn (mg/L)	Cd (μg/L)	PCB (μg/L)	CHP (μg/L)
Gates-Chili-Ogden	0.09(2)	0.11(2)	2.2(2)	<0.1	0.2(p-p-DDT)
Raw Influent	0.08(2)	0.05(2)	2.8(2)	-	-
Primary Effluent	0.08(2)	0.05(2)	<0.5(2)	<0.01	<0.01
Secondary Effluent					
Frank Van Lare					
Raw Influent	0.02(3)	0.15(3)	2.1(3)	<0.03	0.26(Aldrin)
Alum Effluent	0.02(3)	0.09(3)	***	<0.01	0.14(Aldrin)
Biological Effluent	0.02(3)	0.06(3)	3.3(3)	<0.01	<0.01
Big Sister Creek					
Raw Influent	0.06(2)	0.21(2)	<0.5(2)	<0.01	<0.01
Secondary Effluent	0.06(2)	0.02(2)	<0.5(2)	<0.01	<0.01
Filtered Effluent	0.07(2)	<0.018(2)	<0.5(2)	<0.01	<0.01
Ely					
Raw Influent	0.04(3)	0.08(3)	<0.5(3)	<0.01	<0.01
Secondary Effluent	0.02(3)	0.03(3)	<0.5(3)	<0.01	<0.01
Filtered Effluent	0.02(3)	0.02(3)	<0.5(3)	<0.01	0.09(Aldrin)

* Number in parentheses indicates the number of samples analyzed. Detection limits for the metals were: 0.02 mg Ni/L, 0.5 μg Cd/L, and 0.018 mg Zn/L.

** Concentration of organics which were too low for quantification are reported as less than (<) the analytical limit for the methods used. Specifically quantified pesticides are given in parentheses.

*** Samples lost

the Ely plant and in both the raw and alum-treated primary effluent at the Frank Van Lare plant. The relative magnitude of the concentrations measured in the Van Lare samples, 0.26 μg/L in the raw influent, 0.14 μg/L in the primary effluent, and < 0.01 μg/L in the biological effluent, suggests that aldrin was removed during both physical-chemical and biological treatment of wastewater. However, the number of samples which contained measurable concentrations of any analate pesticide was inadequate to permit substantive conclusions regarding removal during treatment at the plants investigated.

SECTION 7

STUDIES ON BIOLOGICAL AVAILABILITY OF WASTEWATER PHOSPHORUS

RESULTS OF BIOASSAY STUDIES

To illustrate algal growth and phosphorus uptake during a typical bioassay, Figure 22 shows the response of Scenedesmus sp., in terms of cell volume concentration and algal phosphorus, during a batch bioassay experiment to determine the concentration of biologically available soluble phosphorus in a wastewater sample from the raw influent to the Ely plant. As indicated in Figure 22, the algae in the batch system were harvested and replaced with phosphorus-starved algae on days 4 and 8. The growth of test culture between harvest periods is shown on the left axis of Figure 22 as the logarithm of the cell volume concentration during growth. From the cell volume concentration data it is apparent that significant algal growth occurred only during the first 4-day incubation period. The phosphorus uptake data show that approximately 91 percent of the algal phosphorus uptake which was measured in the bioassay, occurred during the first four day period. However, as shown in Figure 22, additional phosphorus uptake occurred during succeeding incubation periods, even though the algal biomass failed to increase or actually decreased. Also shown in Figure 22 is the total soluble phosphorus concentration of the bioassay medium, which was approximately 200 μg P/L. Not shown in the figure is the soluble reactive phosphorus concentration which was 127 μg P/L or approximately 64 percent of the total soluble phosphorus. However, as Figure 22 shows, the algal uptake of soluble phosphorus amounted to 158 μg P/L during the initial 4-day incubation period, or approximately 80 percent of the total soluble wastewater phosphorus which was present initially. Clearly short-term uptake amounted to more phosphorus than the initial soluble reactive phosphorus.

Phosphorus taken up by the algae during the first 4-day incubation amounted to nearly 91 percent of the 173 μg P/L which had become available to the algae by the termination of the bioassay. As for the soluble phosphorus bioavailability assay presented in Figure 22, it was generally true for all bioassays, for both soluble and particulate, that the majority of the phosphorus which became available, did so during the first 3-5 days of incubation.

Presented in Tables 18 through 21 are the results of the phosphorus availability bioassays for available particulate and soluble phosphorus in wastewater samples taken from each of the four monitored wastewater plants. Additionally, Tables 18 through 21 contain a detailed chemical characterization of the phosphorus in the wastewater samples as determined at the

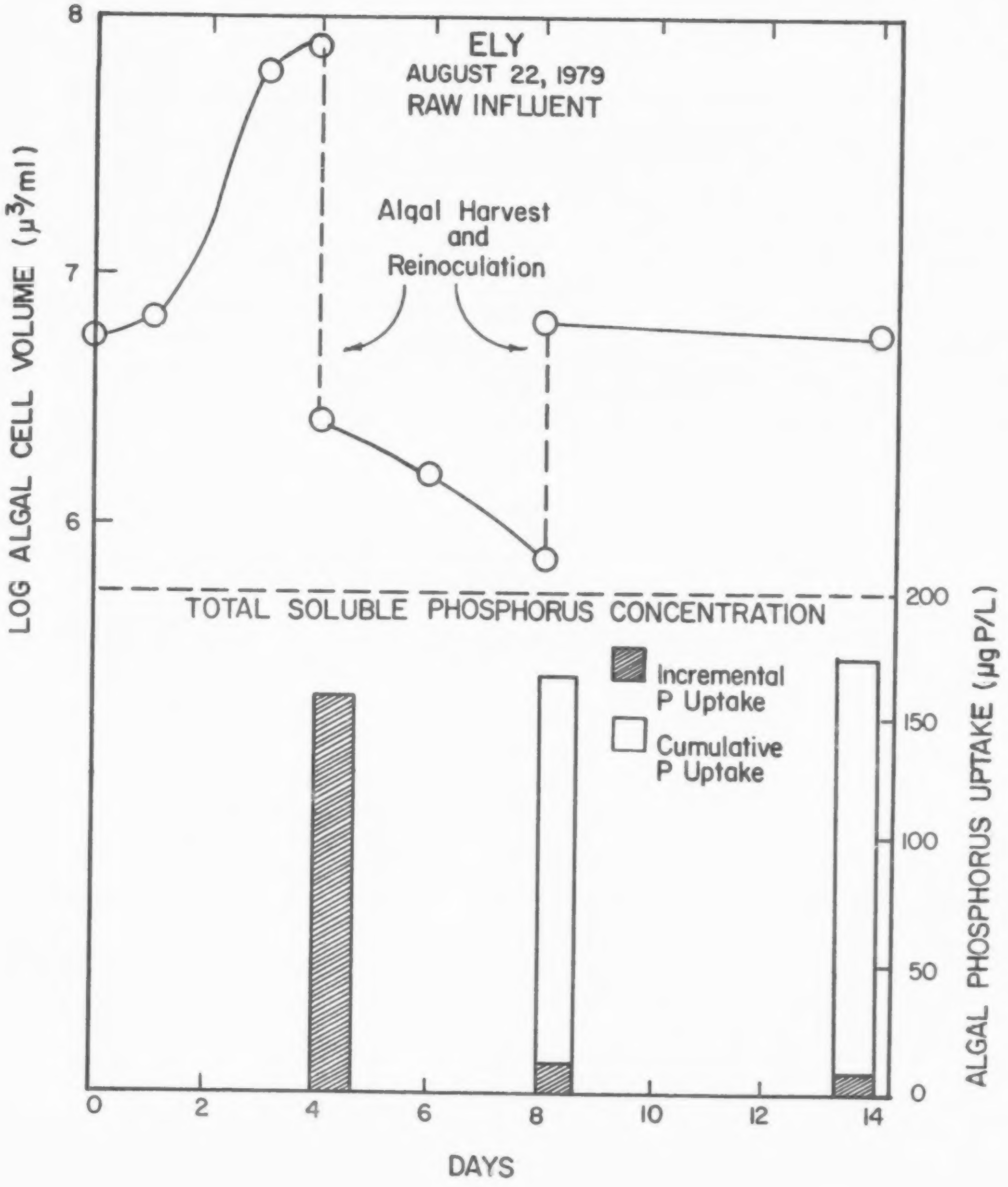

Figure 22. Algal growth and phosphorus uptake during a bioassay to determine available soluble phosphorus

TABLE 18. RESULTS OF PHOSPHORUS AVAILABILITY BIOASSAYS ON WASTE-WATER SAMPLES FROM GATES-CHILI-OGDEN PLANT

Measured Parameter*	Sampling Date**					
	July 3, 1979			July 12, 1979		
	Raw Influent (1)	Primary Effluent	Final Effluent (2)	Raw Influent	Primary Effluent (1)	Final Effluent (2)
Chemical Assay						
TP	6.60		0.92	5.76	4.95	1.28
TPP	2.60		0.55	2.16	1.20	0.66
NaOH-P	2.30		0.54	0.37	0.41	0.55
TSP	4.00		0.37	3.60	3.75	0.62
SRP	2.56		0.08	2.48	2.36	0.08
Biological Assay						
Particulate						
BAPP	1.60		0.34		0.82	0.58
Error***	1		13		9	6
Soluble						
BASP	2.36		0.13		2.14	0.27
Error	8		10		7	24
TBAP	3.96		0.47		2.96	0.85

* Phosphorus concentrations given in mg P/L:
Tp = total phosphorus
TPP = total particulate phosphorus
NaOH-P = total NaOH extractable phosphorus
TSP = total soluble phosphorus
SRP = soluble reactive phosphorus
BAPP = biologically available particulate phosphorus
BASP = biologically available soluble phosphorus
TBAP = biologically available phosphorus
TBAP = BAPP + BASP

** Replication of BAPP bioassays is indicated by the number in parentheses; BASP bioassays were not replicated.

*** Error = percent error in mass balance.

TABLE 19. RESULTS OF PHOSPHORUS AVAILABILITY BIOASSAYS ON WASTEWATER SAMPLES FROM FRANK VAN LARE PLANT*

Measured Parameter	Sampling Date July 17, 1979 Raw Influent (1)	Bio-logical (1)	Secondary Effluent (1)	July 27, 1979 Raw Influent (2)	Bio-logical (1)	Secondary Effluent (2)
Chemical Assay						
TP	2.72	2.34	2.42	3.28	2.17	0.58
TPP	0.88	0.96	0.84	1.18	1.03	0.36
NaOH-P	0.55	0.76	0.10	0.15	0.56	0.22
TSP	1.84	1.38	1.58	2.10	1.14	0.22
SRP	1.63	0.89	1.38	1.58	0.97	0.14
Biological Assay						
Particulate						
BAPP	0.32	0.56	0.51	0.63	0.68	0.16
Error	8	6	19	6	5	4
Soluble						
BASP	1.83	1.00	1.26	1.62	1.03	0.20
Error	13	6	15	9	11	18
TBAP	2.15	1.56	1.77	2.24	1.71	0.36

* See Legend, Table 18

TABLE 20. RESULTS OF PHOSPHORUS AVAILABILITY BIOASSAYS ON WASTEWATER SAMPLES FROM BIG SISTER CREEK PLANT*

Measured Parameter	Sampling Date					
	July 31, 1979			August 10, 1979		
	Raw Influent (2)	Secondary Effluent (1)	Final Effluent (2)	Raw Influent (2)	Secondary Effluent (1)	Final Effluent (1)
Chemical Assay						
TP	7.03	2.46	1.03	4.77	2.02	0.86
TPP	1.95	0.08	0.04	1.17	0.17	0.07
NaOH-P	1.37	0.01	0.03	1.04	0.09	0.94
TSP	5.08	2.37	0.99	3.60	1.86	0.79
SRP	4.77	2.11	0.86	1.49	1.15	0.41
Biological Assay						
Particulate						
BAPP	0.97	0.05	0.02	0.37	0.05	0.02
Error	4	1	14	-8	25	20
Soluble						
BASP	5.08	2.29	0.85	3.15	1.58	0.57
Error	24	12	5	9	9	21
TBAP	6.04	2.34	0.87	3.52	1.63	0.59

* See Legend, Table 18

TABLE 21. RESULTS OF PHOSPHORUS AVAILABILITY BIOASSAYS ON WASTEWATER SAMPLES FROM ELY PLANT*

Measured Parameter	Sampling Date					
	August 14, 1979			August 22, 1979		
	Raw Influent (2)	Secondary Effluent (2)	Final Effluent (2)	Raw Influent (2)	Secondary Effluent (2)	Final Effluent (2)
Chemical Assay						
TP	4.78	1.38	0.27	2.36	1.17	0.71
TPP	2.62	1.26	0.24	1.03	1.05	0.62
NaOH-P	1.06	0.71	0.19	0.09	0.62	0.25
TSP	2.16	0.12	0.02	1.33	0.12	0.08
SRP	1.13	0.00	0.00	0.85	0.00	0.01
Biological Assay						
Particulate						
BAPP	1.34	0.76	0.12	0.69	0.70	0.47
Error	27	21	31	6	18	12
Soluble						
BASP	1.73	0.11	0.02	1.16	0.11	0.08
Error	12	17	33	10	6	25
TBAP	3.07	0.87	0.13	1.84	0.81	0.55

* See Legend, Table 18

beginning of each bioassay. Bioassay replication was generally as duplicates on each sample for particulate phosphorus for the dates indicated in the tables. Soluble phosphorus bioassays were not replicated. Lastly, Tables 18 through 21 contain values for the error in the phosphorus mass balances which were required for calculation of the biologically available particulate phosphorus and biologically available soluble phosphorus from the bioassay data.

Mass balance errors were calculated according to the relationship:

$$E(\%) = \frac{\Sigma(\text{Algal P}) - \Delta(\text{Wastewater P})}{(\text{Initial Wastewater P})} \times 100\%$$

where: E(%) = Mass balance error, percent;

Σ(Algal P) = Mass of algal phosphorus harvested from assay vessel during the algal bioassay, corrected for phosphorus in phosphorus-starved assay cultures and inocula, μg P.

Δ(Wastewater P) = Change in the mass of phosphorus fraction in the decay vessel from initiation to termination, μg P.

The error in the mass balances ranged from -8 to 31 percent with an average error of 11 percent for the particulate phosphorus bioassays and ranged from 5 to 33 percent with an average error of 14 percent for the soluble phosphorus bioassays.

The results given in Tables 18 through 21 are illustrated in Figures 23 through 26 as bar diagrams which show the biologically available and non-available portions of total phosphorus, total particulate phosphorus, and total soluble phosphorus in samples taken through the four wastewater plants. It is clear from the data in Figures 23 through 26 that biologically available phosphorus in the raw wastewater influent to each plant was reduced in concentration during treatment.

Effects of Treatment on Biologically-Available Phosphorus

To facilitate an examination of the effects of wastewater treatment on the biologically available fraction of wastewater phosphorus, the chemical and biological phosphorus data in Tables 18 through 21 were used to calculate average amounts of biologically available phosphorus relative to the soluble, particulate, and total phosphorus in the wastewater during various stages of treatment. This required calculation of the ratios:TBAP/TP, BAPP/TPP, and BASP/TSP,

where: BAPP = Biologically available particulate phosphorus, μg P/L;

BASP = Biologically available soluble phosphorus, μg P/L;

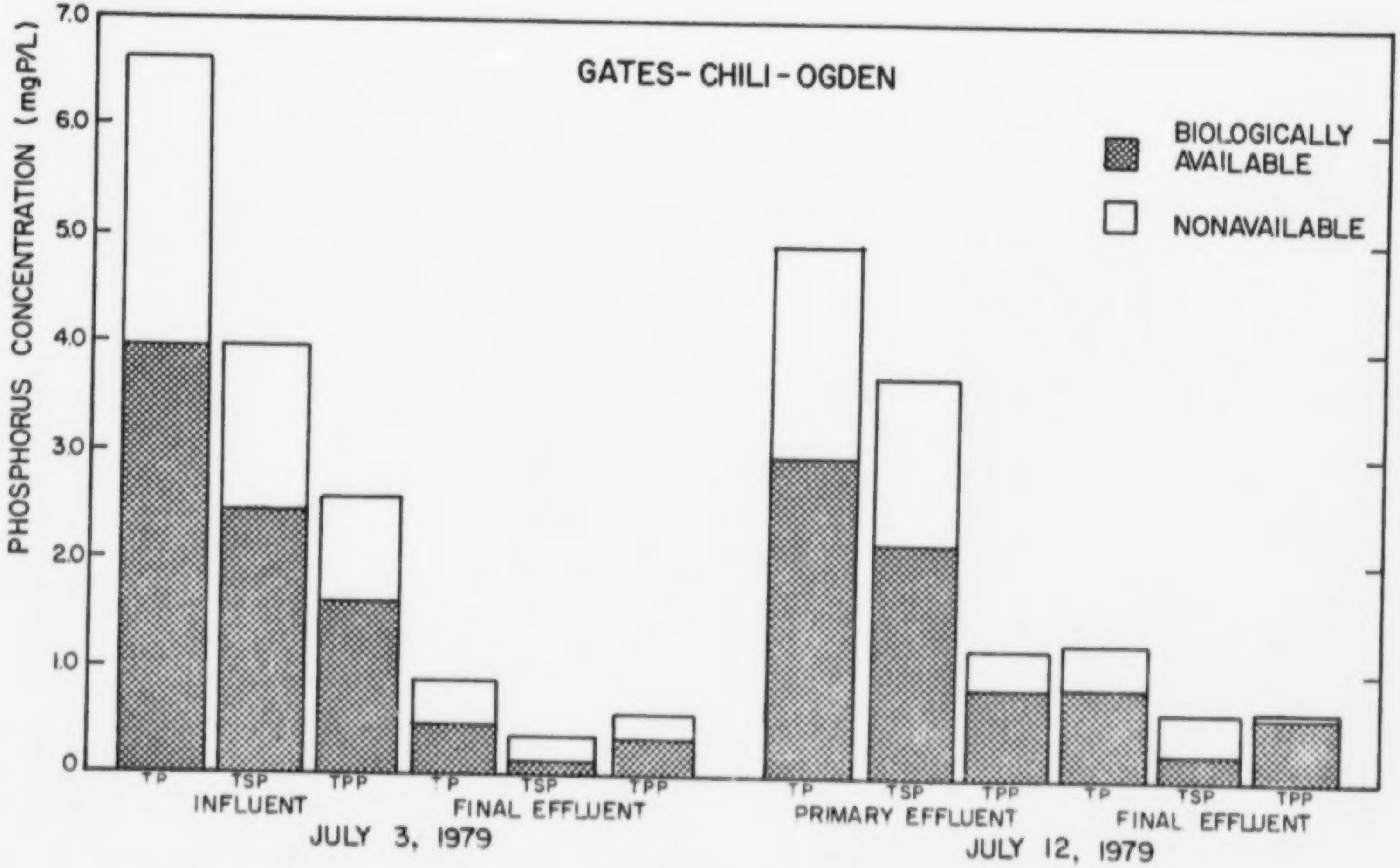

Figure 23. Biologically available and non-available fractions of phosphorus in wastewater samples from the Gates-Chili-Ogden plant

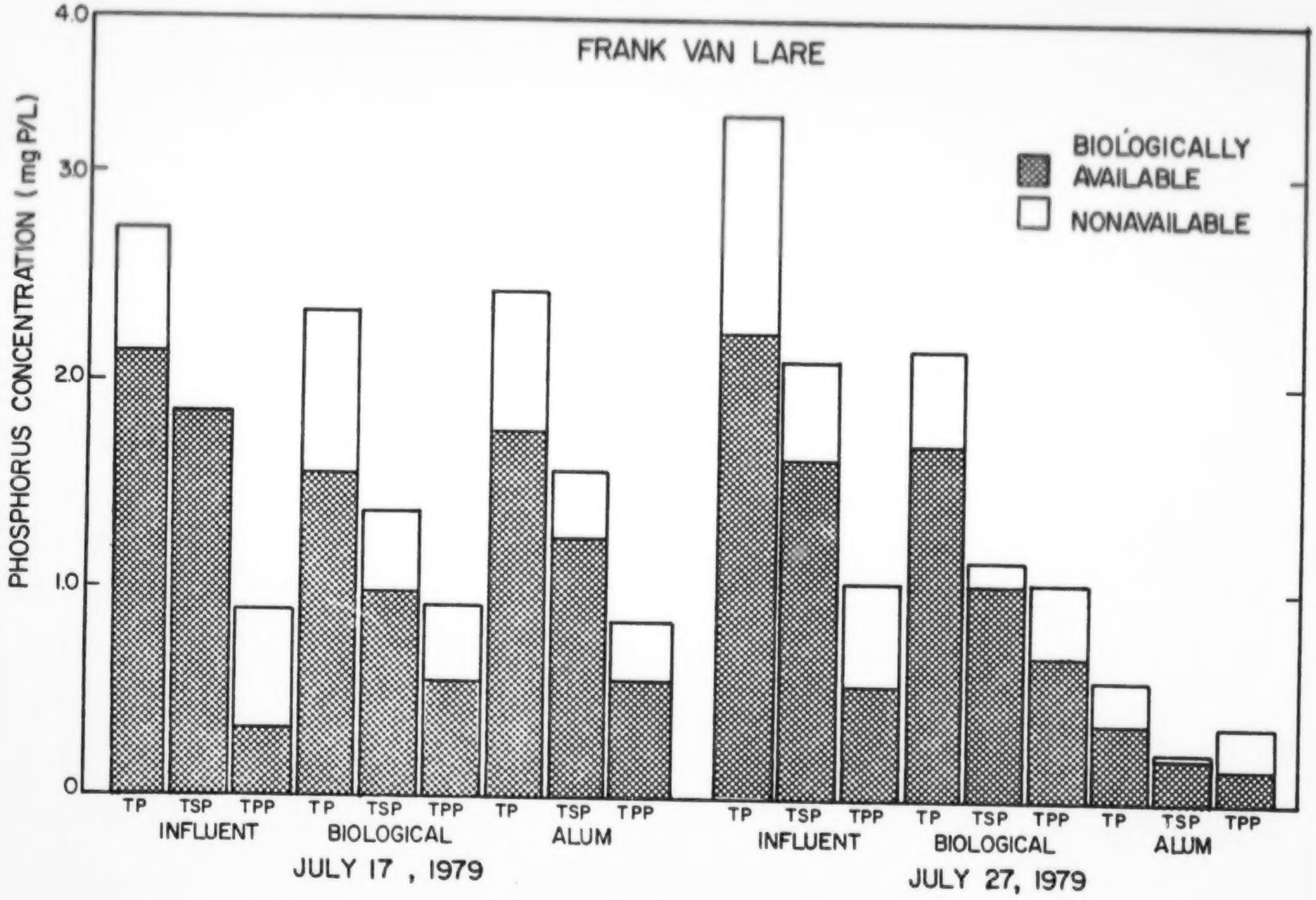

Figure 24. Biologically available and non-available fractions of phosphorus in wastewater samples from the Frank Van Lare plant

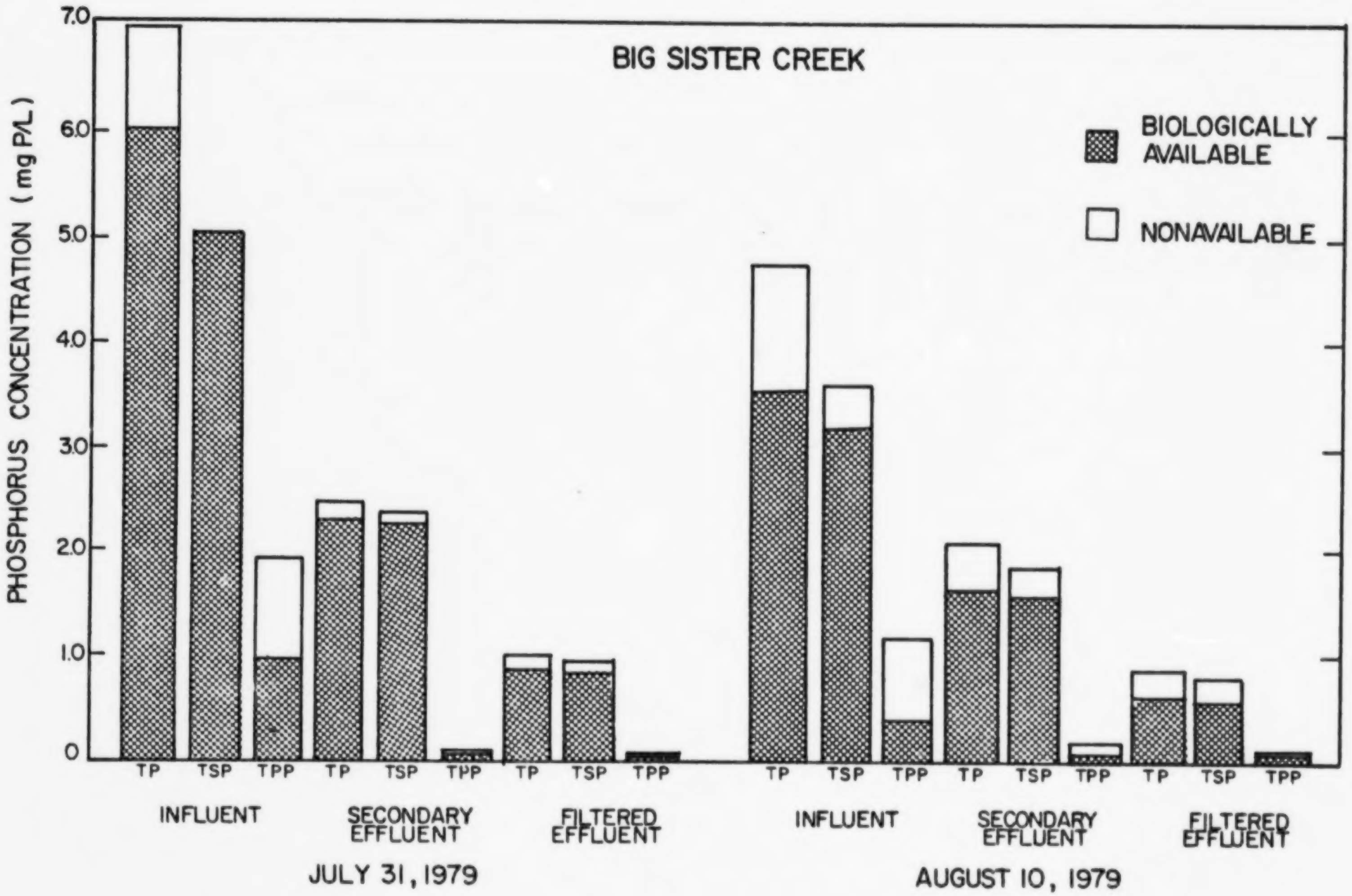

Figure 25. Biologically available and non-available fractions of phosphorus in wastewater samples from the Big Sister Creek plant

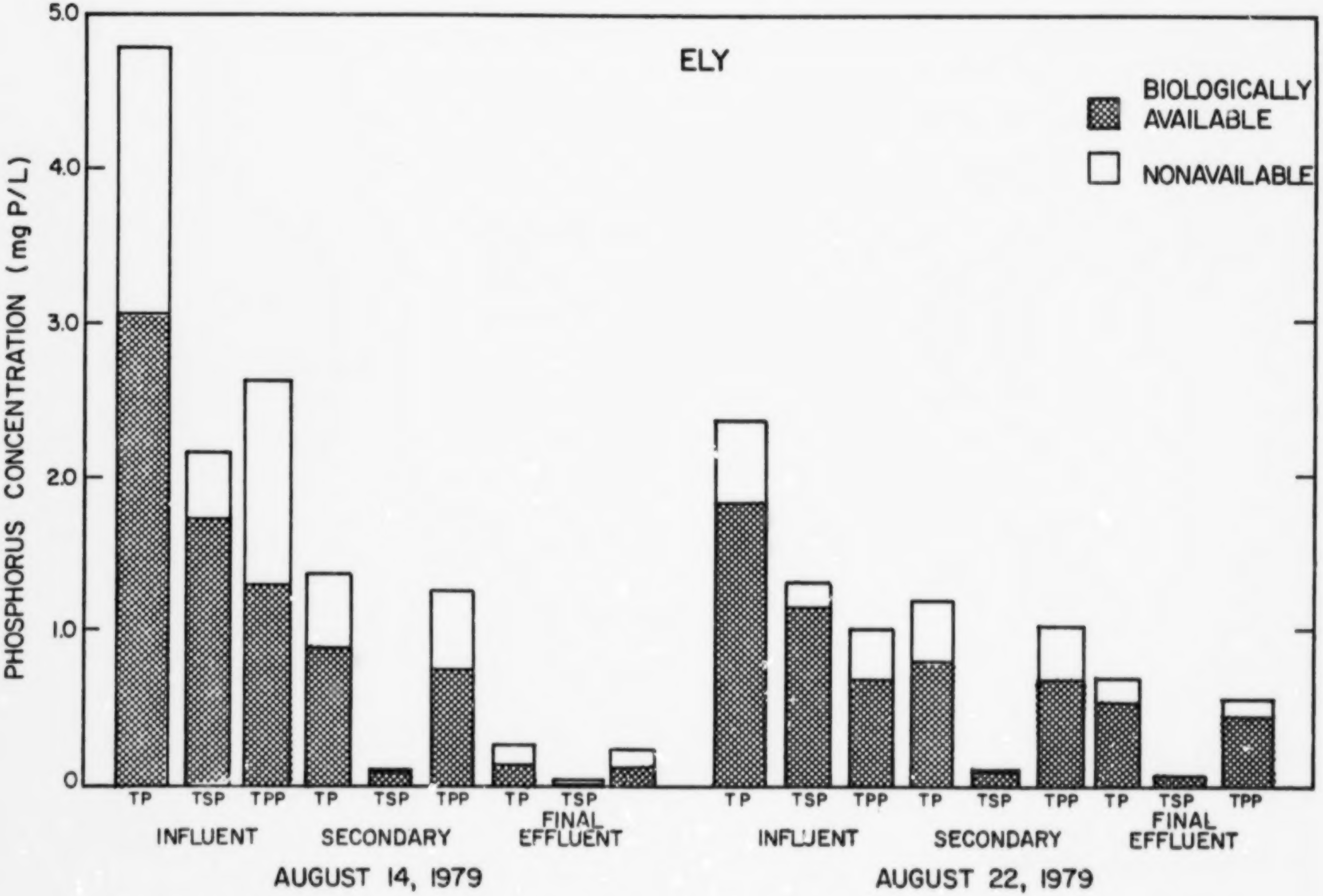

Figure 26. Biologically available and non-available fractions of phosphorus in wastewater samples from the Ely plant

TBAP = Total biologically available phosphorus, BAPP + BASP, μg P/L;

TP = Total phosphorus, μg P/L;

TPP = Total particulate phosphorus, μg P/L;

TSP = Total soluble phosphorus, μg P/L

Additionally, the data were used to calculate estimates of the percentage reduction of raw wastewater TBAP, BAPP, and BASP at the sampling locations in each treatment plant. The ratios and removal data are given in Table 22.

The data on the amount of available phosphorus in the soluble, particulate, and total phosphorus fractions of wastewater shows little variation in available phosphorus as a proportionate component during treatment. The lack of variation is particularly evident in the amount of TBAP (BAPP + BASP) relative to the total phosphorus during treatment. The ratio, TBAP/TP, in raw wastewater varied from 0.6 to 0.8 among the wastewater plants. However, within any particular plant the ratio varied over a considerably smaller range through the treatment stream. Thus it appears that raw wastewater characteristics, as yet unidentified, play a greater role in determining the overall extent of biological availability of phosphorus in treated effluents than the methods employed during wastewater treatment, at least with a respect to the methods encountered during this investigation. Similarly the proportions: BAPP/TPP and BASP/TSP in wastewater were more variable among plants than between stages of treatment within any particular plant. The only exception to the apparent lack of in-plant variation in available phosphorus as a component of the wastewater phosphorus occurred at the Frank Van Lare plant, where the amount of BAPP relative to TPP was quite variable. However, the BASP relative to TSP through the Van Lare plant showed little change.

Removal of Biologically Available Phosphorus

A comparison of data on the removal of total phosphorus and the phosphorus fractions, given in Table 16, with the removal of biologically available phosphorus, set forth in Table 22, shows similar percentage removals for available fractions and corresponding, analytically-defined chemical fractions of wastewater phosphorus, with the exception of the Frank Van Lare plant. Available phosphorus in the raw influent at the Van Lare plant was removed less efficiently than the analytically-defined components of phosphorus. Among the three other wastewater plants, the percentage removals of total phosphorus ranged from 85 to 88 percent (Table 16), while total available phosphorus removal (TBAP) ranged from 83 to 88 percent (Table 22). Percent removals of biologically-available and total quantities of soluble and particulate wastewater phosphorus were similar.

CHEMICAL FRACTIONS AND BIOLOGICALLY AVAILABLE PHOSPHORUS

A major objective of this investigation was to determine the extent to which available phosphorus, as determined by algal bioassay, may be related

TABLE 22. PERCENTAGES OF BIOLOGICALLY AVAILABLE PHOSPHORUS AND REDUCTION IN BIOLOGICALLY AVAILABLE PHOSPHORUS AT MONITORED WASTEWATER PLANTS

	Percent					
	Biologically Available Phosphorus			Reduction of Biologically Available Phosphorus Compared to Raw Influent		
Plant Name and Sampling Location*	$\frac{TBAP}{TP}$	$\frac{BAPP}{TPP}$	$\frac{BASP}{TSP}$	TBAP	BAPP	BASP
Gates-Chili-Ogden						
Raw Influent (1)	60	62	59	-	-	-
Primary Effluent (1)	60	68	57	-	-	-
Secondary Effluent (2)	58	74	40	88	79	94
Frank Van Lare						
Raw Influent (2)	72	44	88	-	-	-
Alum Effluent (2)	68	52	86	51	12	59
Biological Effluent (2)	73	62	82	26	38	41
Big Sister Creek						
Raw Influent (2)	80	40	94	-	-	-
Secondary Effluent (2)	88	48	91	58	90	53
Filtered Effluent (2)	76	40	79	85	96	83
Ely						
Raw Influent (2)	71	59	82	-	-	-
Secondary Effluent (2)	66	63	92	64	21	92
Filtered Effluent (2)	64	62	86	83	62	96

* Number of samples assayed is given in parentheses.

to and predicted from chemical assays of phosphorus in wastewater. The approach taken toward achieving this objective focused on examining the biological availability data, from the wastewater samples collected at the treatment plants, for correlations with the different chemical fractions of wastewater phosphorus which were measured at the time each bioassay was initiated.

Given in Table 23 are zero-order correlation coefficients between biologically assayed available phosphorus and chemically assayed fractions of phosphorus for all the wastewater samples for which bioassays were performed. Thus, the correlation coefficients listed in Table 23 represent the extent of relationship between available and chemical fractions of phosphorus which occur in wastewater samples from different wastewater plants and differing stages of treatment.

Available Soluble Phosphorus

Biologically available soluble phosphorus correlated strongly and nearly equally ($r > 0.95$, $\alpha < 0.01$) with both total soluble phosphorus and soluble reactive phosphorus. Such a result is not unexpected as soluble reactive phosphorus is considered widely to be the phosphorus form used directly for algal growth. Since soluble reactive phosphorus was a major component of the soluble phosphorus in the wastewaters employed in this investigation, any correlation between biologically available soluble phosphorus and soluble reactive phosphorus would be reflected in a coincident correlation with total soluble phosphorus. However, biologically available soluble phosphorus was a consistently larger fraction of the total soluble phosphorus than was soluble reactive phosphorus. Available soluble phosphorus averaged 80 percent of the total soluble, while soluble reactive phosphorus averaged 69 percent of the total soluble, as may be determined from Tables 18-21. Thus, a significant fraction of the nonreactive soluble phosphorus of wastewater became available during the limited periods of incubation of the bioassay studies.

Another view of the biological availability of the soluble wastewater phosphorus as it compared between plants and samples is shown in Figure 27. In Figure 27 biologically available soluble phosphorus is plotted against total soluble phosphorus for the four plants studied intensively. The degree of association between the two measures of phosphorus, the apparent similarity of availability of soluble phosphorus between the different treatment plants, and the lack of a non-zero intercept in the regression equation which relates the two quantities, serve to support the conclusion that the biological availability of soluble wastewater phosphorus is unaltered during treatment by common treatment methods, including chemical precipitation for phosphorus removal. That is, phosphorus removal as it occurs during wastewater treatment does not selectively remove either available or non-available soluble phosphorus. Consequently, efforts to manage the discharge of biologically available soluble phosphorus in wastewater effluents must focus on removal of the total soluble fraction to maximize removal of available soluble phosphorus.

TABLE 23. SUMMARY STATISTICAL PARAMETERS AND CORRELATION COEFFICIENTS FOR CHEMICALLY AND BIOLOGICALLY ASSAYED PHOSPHORUS IN 22 WASTEWATER SAMPLES*

Chemically Assayed Phosphorus	Biologically Available Phosphorus BASP	 BAPP	 TBAP
	Correlation Coefficients		
TP	0.885	0.705	0.968
TPP	0.488	0.959	0.700
NaOH-P	0.477	0.795	0.643
TSP	0.952	0.469	0.958
SRP	0.951	0.393	0.935
NaOH + SRP	0.913	0.598	0.962

* $r_{crit,\ 0.05} = 0.423$; $r_{crit,\ 0.01} = 0.537$

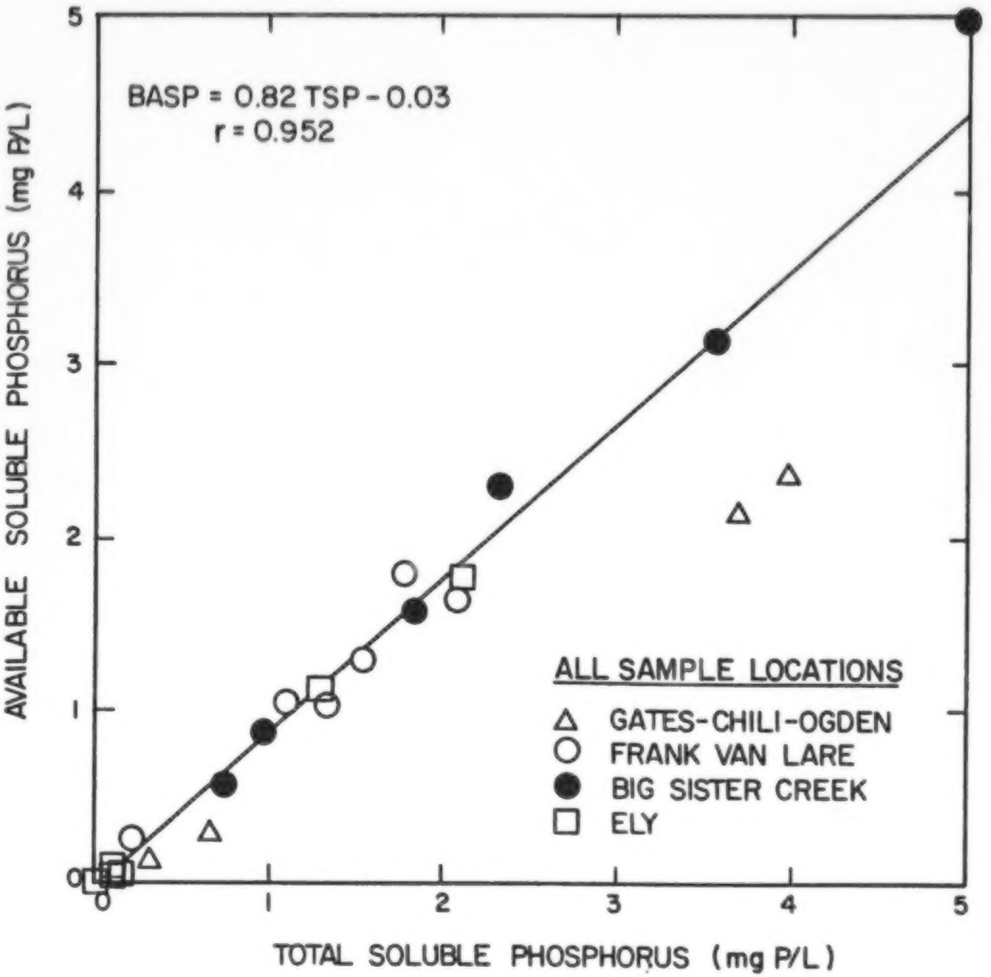

Figure 27. Biologically available soluble phosphorus as a function of total soluble phosphorus in wastewater samples

The relationship between biologically available soluble phosphorus and soluble reactive phosphrous in the wastewater samples is illustrated in Figure 28, for an analysis similar to the previous involving total soluble phosphorus. Though the intercept of the regression was not shown statistically to be different from zero (p~0.09), the regression suggests that generally more soluble phosphorus was available than that fraction measured as soluble reactive phosphorus. However, the regression coefficient relating BASP to SRP was essentially unity which indicates the soluble phosphorus in wastewater which is measured as reactive by the analytical test described earlier, is totally available for organism growth.

Available Particulate Phosphorus

As shown in Table 23, biologically available particulate phosphorus correlated most closely ($r = 0.959$, $\alpha < 0.01$) with the total particulate fraction of the wastewater samples. The particulate phosphorus which could be extracted with NaOH also correlated with available particulate phosphorus, but the correlation was weaker ($r = 0.795$, $\alpha < 0.01$) than that involving total particulate phosphorus. The relationship between BAPP and TPP is illustrated in Figure 29, which shows BAPP as a function of TPP. The linear relationship shown by the data in Figure 29 suggest that the availability of particulate phosphorus is affected only to a minor extent during wastewater treatment, a similar result to that given earlier for soluble phosphorus. That is, the fraction of the total particulate phosphorus of wastewater which can become available to support algal growth remains relatively constant during treatment, including those phases designed to remove phosphorus. Thus, neither available nor non-available particulate phosphorus in wastewater is removed selectively during treatment; rather, each fraction is removed in approximately the same proportion as contained in the raw wastewater which enters the treatment plant. Thus, as was stated earlier concerning efforts to control the discharge of biologically available soluble phosphorus, control of available particulate phosphorus in wastewater effluents should concentrate on the total particulate phosphorus fraction.

A comparison of the data in Figures 27 and 29 indicates a significantly lower proportion of available particulate phosphorus as compared to available soluble phosphorus, relative to the total particulate and soluble fractions. The regression coefficients which relate the biologically available soluble and particulate phosphorus to the total amount of each fraction along with their standard errors were 0.82 ± 0.06 mg BASP/mg TSP and 0.55 ± 0.04 mg BAPP/mg TPP. A similar comparison, calculated from the average value of the phosphorus fractions for all bioassay determinations as given in Tables 18-21, yields 0.81 mg BASP/mg TSP and 0.56 mg BAPP/mg TPP. These data indicate that equal quantities of soluble and particulate phosphorus in a given wastewater would support more algal growth from the phosphorus contained in the soluble fraction than from the particulate fraction. Thus, in terms of phosphorus removal and its relationship to objectives for water quality management, emphasis should be placed on minimizing the total soluble phosphorus concentration of wastewater effluents.

Much has been written about relationship between the availability of particulate phosphorus to aquatic organisms and the extractability of

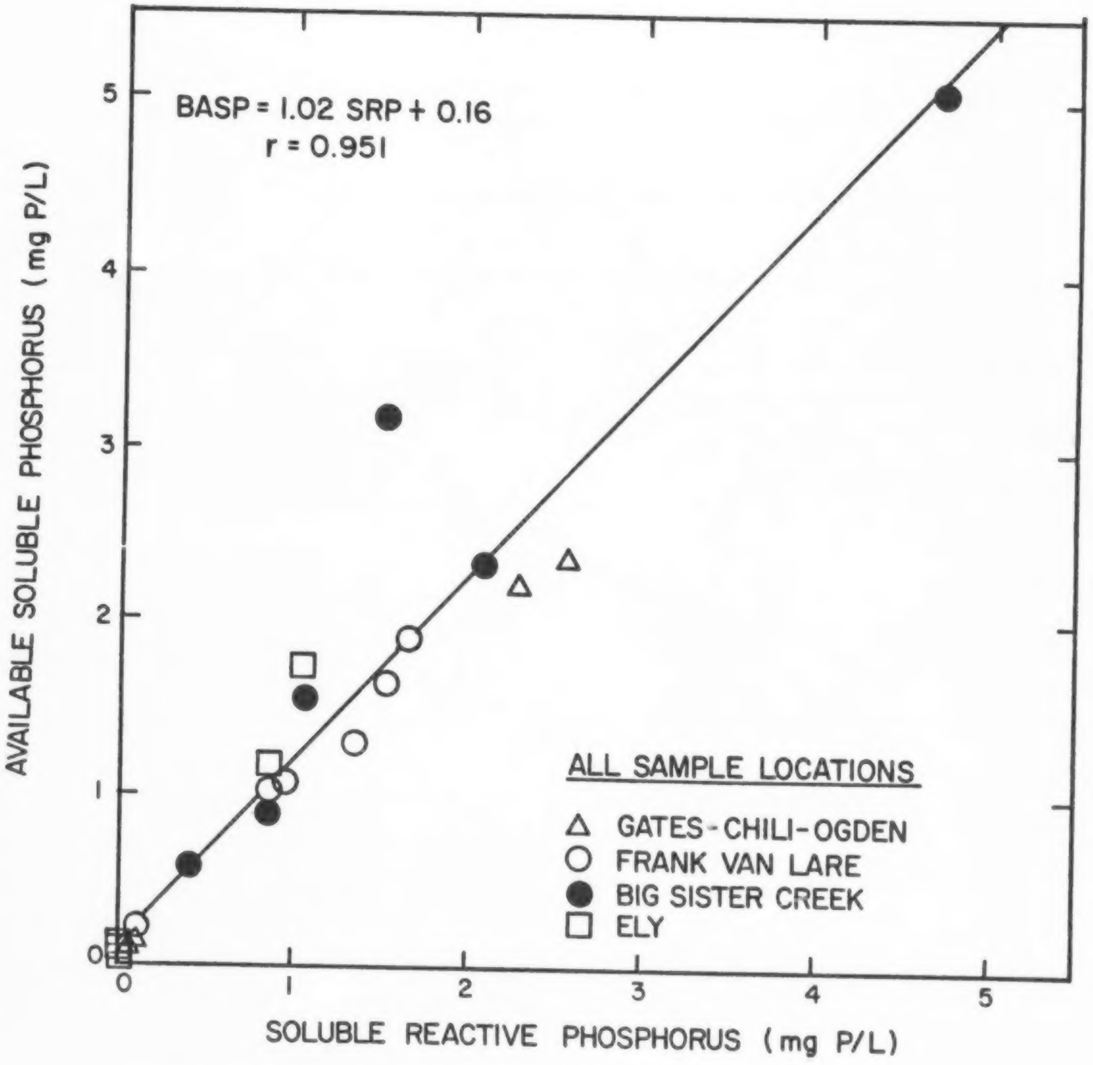

Figure 28. Biologically available s-luble phosphorus as a function of soluble reactive phosphorus in wastewater samples

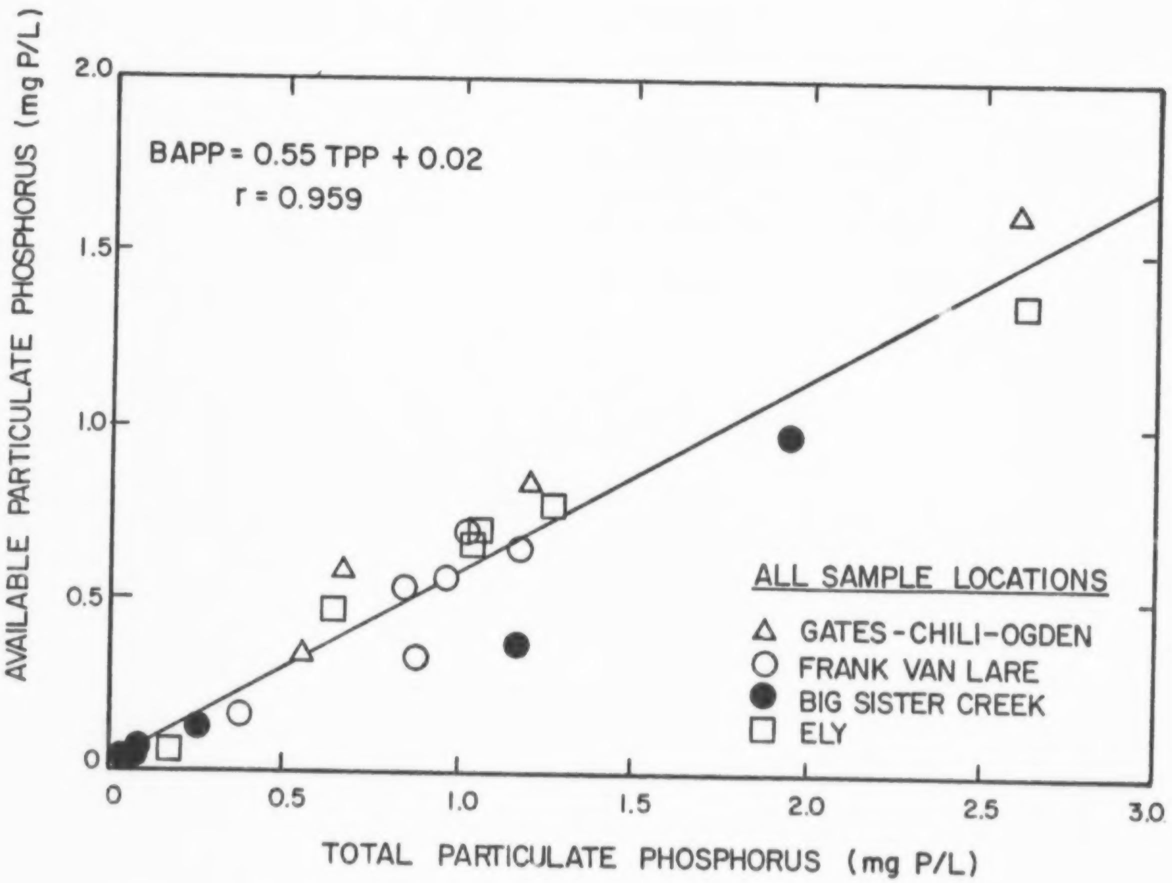

Figure 29. Biologically available particulate phosphorus as a function of total particulate phosphorus in wastewater samples

inorganic phosphorus from aquatic particulates by a 0.1 N solution of NaOH (Armstrong et. al., 1971; Wildung et. al.,1977; Cowen and Lee, 1976; Sagher, 1975, 1976; Logan et. al., 1979). As indicated in Table 23 and illustrated in Figure 30 the relationship between BAPP and the phosphorus extracted from wastewater particulates by 0.1 N NaOH, according to the method described earlier, was too variable to have much predictive value, though the relationship had significance in a statistical sense ($p < 0.01$). It should be pointed out that the NaOH extractable particulate phosphorus measurements determined during this investigation are not strictly comparable to the methods used by others, such as Cowen and Lee (1976) and Sagher (1976), for comparison of chemical and biological assay results, since the previous workers measured only the reactive inorganic phosphorus content of the extractant solution. During the present work, the total phosphorus content of the base extracts was measured and, thus, would include not only reactive inorganic phosphorus, but also a portion of the organic phosphorus of the particles under investigation. Consequently, if only the inorganic fraction of NaOH extractable particulate phosphorus were biologically available, then NaOH-P reported here should systematically overestimate BAPP. However, such was not the case. As seen in Figure 30, BAPP actually was greater than NaOH-P in 11 of the 22 samples. Furthermore, if the total particulate phosphorus which was extracted by NaOH showed a weak relationship with biologically available particulate phosphorus, due to confounded error from inclusion of base-extractable particulate organic phosphorus, then any relationship between available particulate phosphorus and total particulate phosphorus should be no less confounded. Again, such was not the case and, as reviewed earlier, total and biologically available particulate phosphorus concentrations were strongly correlated among the wastewater samples. Thus, it appears that NaOH extractable particulate phosphorus is an analytical method which has limited utility for predicting phosphorus availability when applied to wastewater samples.

Available Total Phosphorus

The total amount of biologically available phosphorus in the wastewater samples was estimated by summation of the available particulate and available soluble fractions on each sample. The relationships between this "total biologically available phosphorus" fraction (TBAP) and chemically assayed fractions are given in Table 23 in terms of correlation coefficients. As could be anticipated from the foregoing results and discussion, the total biologically available phosphorus in the wastewater samples correlated most strongly ($r = 0.968$, $\alpha < 0.01$) with the total phosphorus. However, a nearly identical degree of correlation ($r = 0.962$, $\alpha < 0.01$) was noted between BAP and the sum of soluble reactive and NaOH extractable phosphorus.

The relationship between TBAP and the chemically assayed forms of phosphorus are illustrated in Figures 31 and 32, where TBAP is given as a function of the chemically measured forms. Regression equations also are given to facilitate a comparison between the two estimators of TBAP.

Averaged over all samples of wastewater subjected to bioassay, TBAP

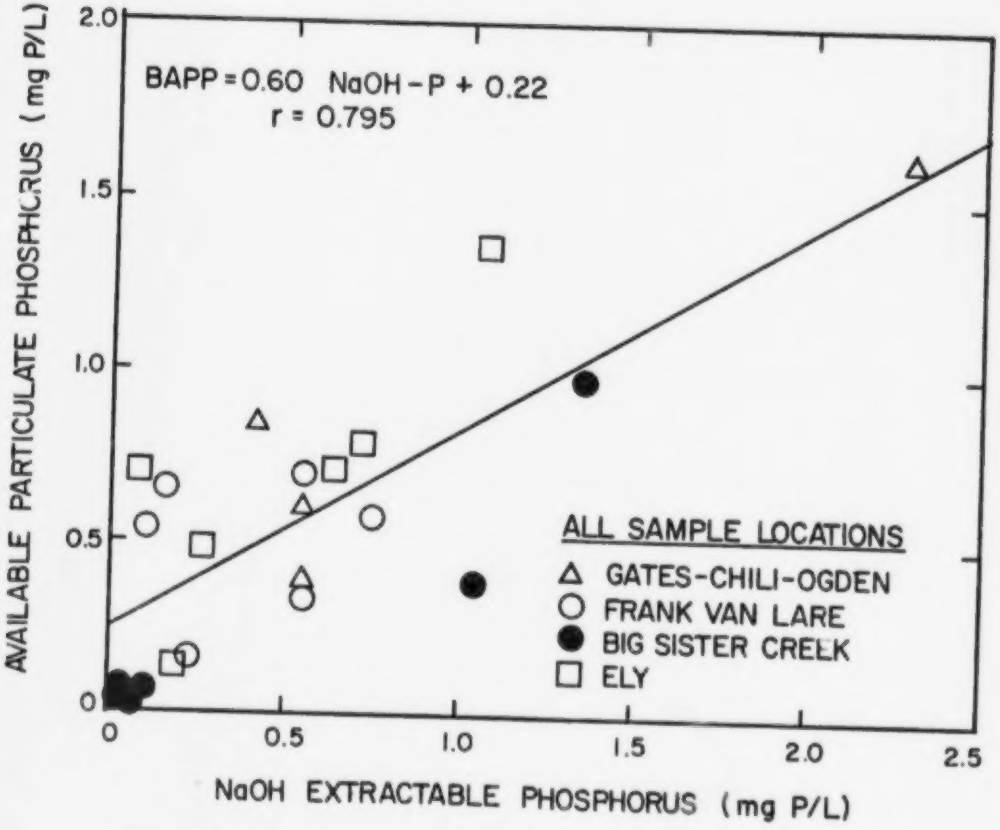

Figure 30. Biologically available particulate phosphorus as a function of NaOH extractable particulate phosphorus in wastewater samples

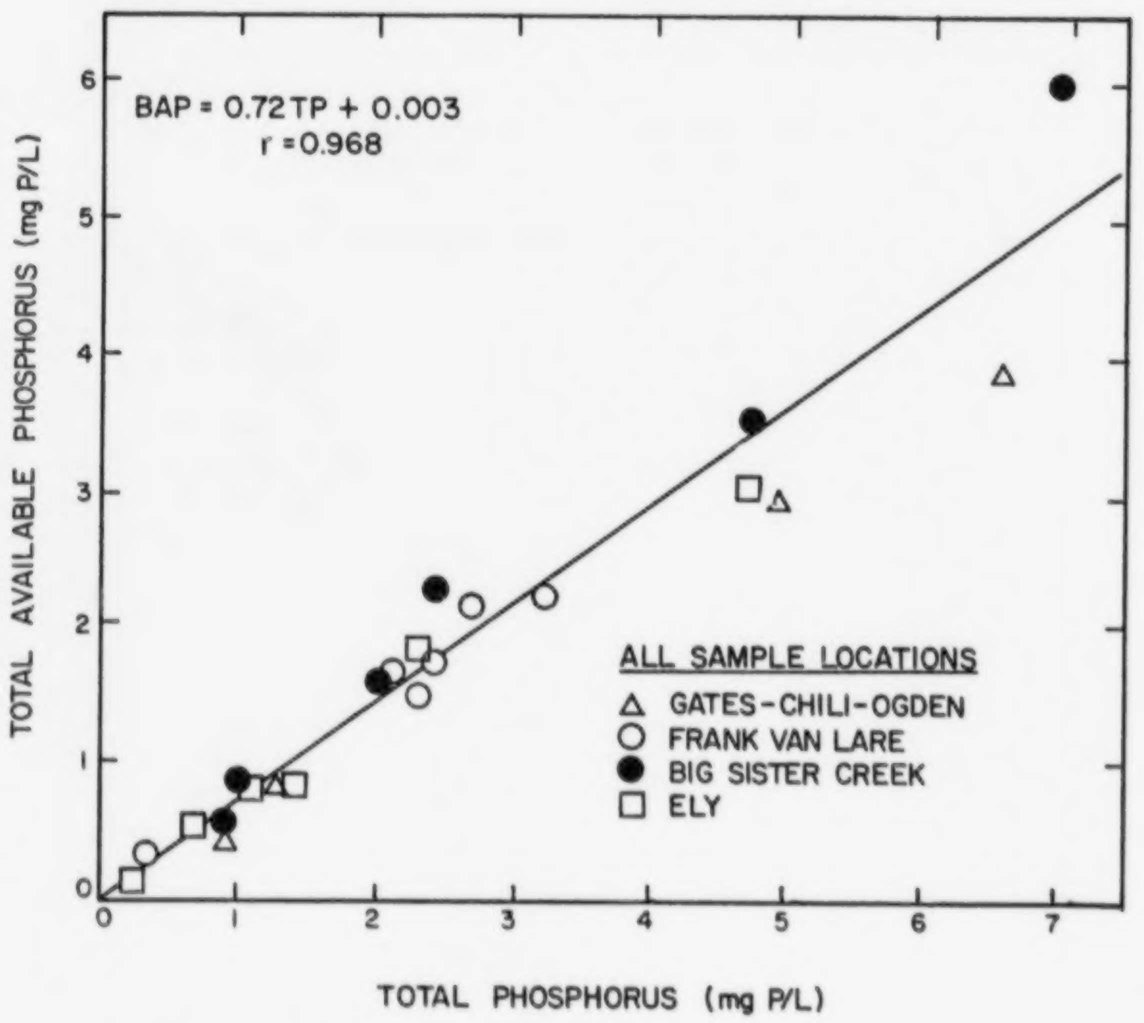

Figure 31. Total biologically available phosphorus as a function of total phosphorus in wastewater samples

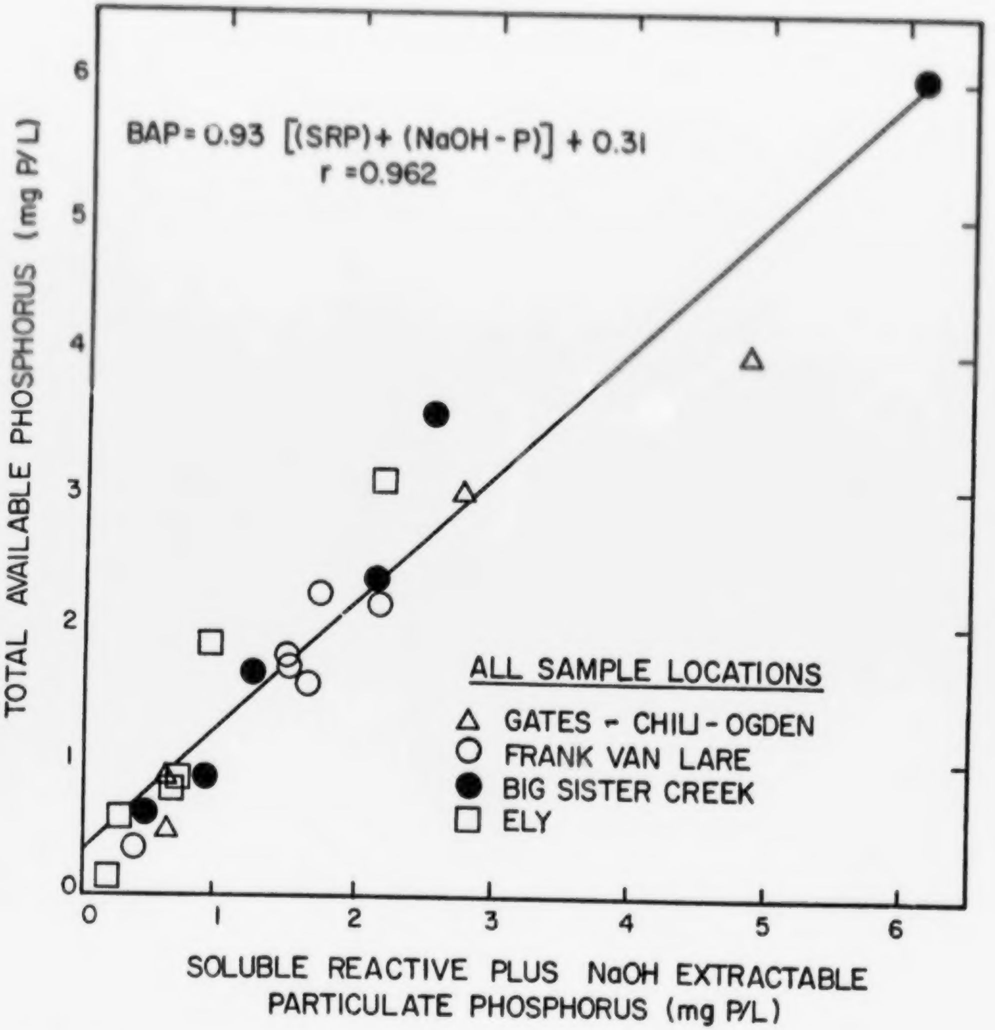

Figure 32. Total biologically available phosphorus as a function of soluble reactive plus NaOH extractable particulate phosphorus in wastewater samples

amounted to 72 percent of the total phosphorus in the samples, as may be calculated from data given in Table 23. That percentage is identical to the regression coefficient shown in Figure 31 for TBAP as a function of total phosphorus concentration. The equality of the two values reflects the nearly uniform proportion of available phosphorus to the total phosphorus in wastewater samples taken from various locations within the treatment plants and the relatively narrow range of values for that proportion among treatment plants.

The sum of soluble reactive plus NaOH extractable phosphorus generally underestimates TBAP. Using values for all the wastewater bioassays, given in Tables 18-21, the TBAP averaged 112 percent of the mean sum of soluble reactive and NaOH extractable phosphorus. The regression coefficient in the equation which relates BAP to the sum of reactive and extractable phosphorus was 0.93, less than would be expected based on the value of the ratio of the mean concentration of the phosphorus fractions. However, examination of Figure 32 suggests that the regression coefficient is strongly biased by two data points which represent relatively low availability. If the points are treated as outliers, possibly as a result of the large dilution factors required for bioassay on such concentrated samples, then the recalculated regression coefficient equals 1.16 and the non-zeros intercept becomes insignificant, leaving a direct relationship between TBAP and (NaOH-P) + (SRP):

$$\text{TBAP} = 1.16\ [(\text{NaOH-P}) + (\text{SRP})] + 0.05$$

$$r = 0.951,$$

which more closely reflects the relative amounts of the biologically and chemically defined fractions. Thus, as an estimator of available phosphorus, the sum of the soluble reactive and NaOH extractable particulate phosphorus appears useful only to obtain an approximate minimum value for total biologically available phosphorus, while a clearly more conservative estimate would be based on the total phosphorus concentration.

A final point needs to be put forth regarding interpretation and applicability of the bioassay data on available phosphorus as presented above. It must be recognized that the bioassays used to estimate the availability of particulate and soluble phosphorus in the wastewater samples were of relatively short duration, due to the time constraints imposed on the investigation. Further, the kinetics of conversion of non-available to available phosphorus were not examined directly. Consequently, reaction orders for the conversion were unknown and the extent of approach of the conversion to ultimate availability at the time of bioassay termination could not be determined. Such considerations should be addressed in future research. However, the criteria for termination of an algal assay: plateaus in biomass increase and accumulation of phosphorus by the assay culture, permitted the availability estimates to approach ultimate availability to the extent that changes in the assay culture were detectable over a period of a few days. The point, then, becomes one of recognizing that the estimates of phosphorus bioavailability and the regression coefficients which relate them to chemically defined phosphorus fractions, as presented in the preceeding, may be less accurate than estimates which are based on truly long-term incubations.

SUMMARY

Algal bioassays were conducted on 22 samples of wastewater, taken from various locations in each of four wastewater treatment plants, to determine the availability of both soluble and particulate phosphorus, to aquatic organisms; and, to determine the extent of relationship, if any, between analytically-defined chemical fractions and bioassay-defined available phosphorus. A comparison of available phosphorus fractions at the different sampling points in each wastewater plant indicated that, at the wastewater plants selected for study, the methods of treatment had no major effect on the biologically available fraction of either soluble or particulate phosphorus relative to the total phosphorus content of those fractions, including phosphorus removal processes. Biologically available phosphorus averaged 72 percent of the total phosphorus, the available particulate fraction averaged 55 percent of the total particulate phosphorus, and the available soluble fraction averaged 82 percent of the total soluble phosphorus concentration in the wastewater samples. Due to its greater availability, soluble phosphorus should be the target fraction for phosphorus removal efforts. Biologically available phosphorus correlated best with the chemically assayed fractions of phosphorus given above. Additional, highly significant correlations were observed between biologically available phosphorus and soluble reactive phosphorus, and between total available phosphorus and the sum of soluble reactive phosphorus and NaOH extractable phosphorus; however, the latter chemically-assayed fractions consistently underestimated biologically available phosphorus.

SECTION 8

COST ANALYSIS

The proper evaluation of a given phosphorus effluent standard requires the costs incurred as well as the benefits obtained. This section will examine operation and maintenance costs associated with phosphorus removal for the four treatment plants studied. Also, for each of these plants, various alternatives will be generated for achieving a phosphorus effluent of 0.5 mg/L. The incremental costs for each of these alternatives will be discussed.

GATES-CHILI-OGDEN

Introduction

The Gates-Chili-Ogden (GCO) wastewater treatment plant is a 20 mgd (7.6×10^4 m^3/day) activated sludge plant located near Rochester, NY. It is operated by the Division of Pure Waters of Monroe County. A description of the GCO wastewater plant and the field data collected at GCO have been presented previously (Section 6). A summary of the phosphorus data and a line schematic diagram of the processes employed are shown in Figure 33.

Since the middle of 1978, phosphorus removal has been practiced at GCO by means of alum precipitation. Liquid alum is added between the aeration basin and the final sedimentation basins. As can be seen from the summary diagram (Figure 33), this approach can result in low phosphrous effluent concentrations. The average effluent concentration was 0.75 mg/L for the sampling period. GCO has a phosphorus effluent standard of 1.0 mg/L.

The liquid alum used at GCO is a 48 percent alum solution and purchased from Allied Chemical. During the sampling period, a dosage of 70.1 mg/L was used, which is equivalent to an Al^{+3} concentration of 3.0 mg/L.

Operation and Maintenance Costs

Total operation and maintenance costs for GCO are presented in Table 24. Note that two periods are shown — one corresponding to a time when phosphorus removal was not being practiced, and one when phosphorus removal was practiced. Each of these periods is the result of six months of actual plant records extrapolated to a one year period. These costs are reported in dollars for their respective periods, and are therefore not indexed. Based on the Consumer Price Index for all urban consumers (CPI-U) (U.S. Dept. of Labor, 1979), the rate of increase was 11.8 percent for August 1978 to August 1979 (unadjusted) for all items in the CPI expenditure

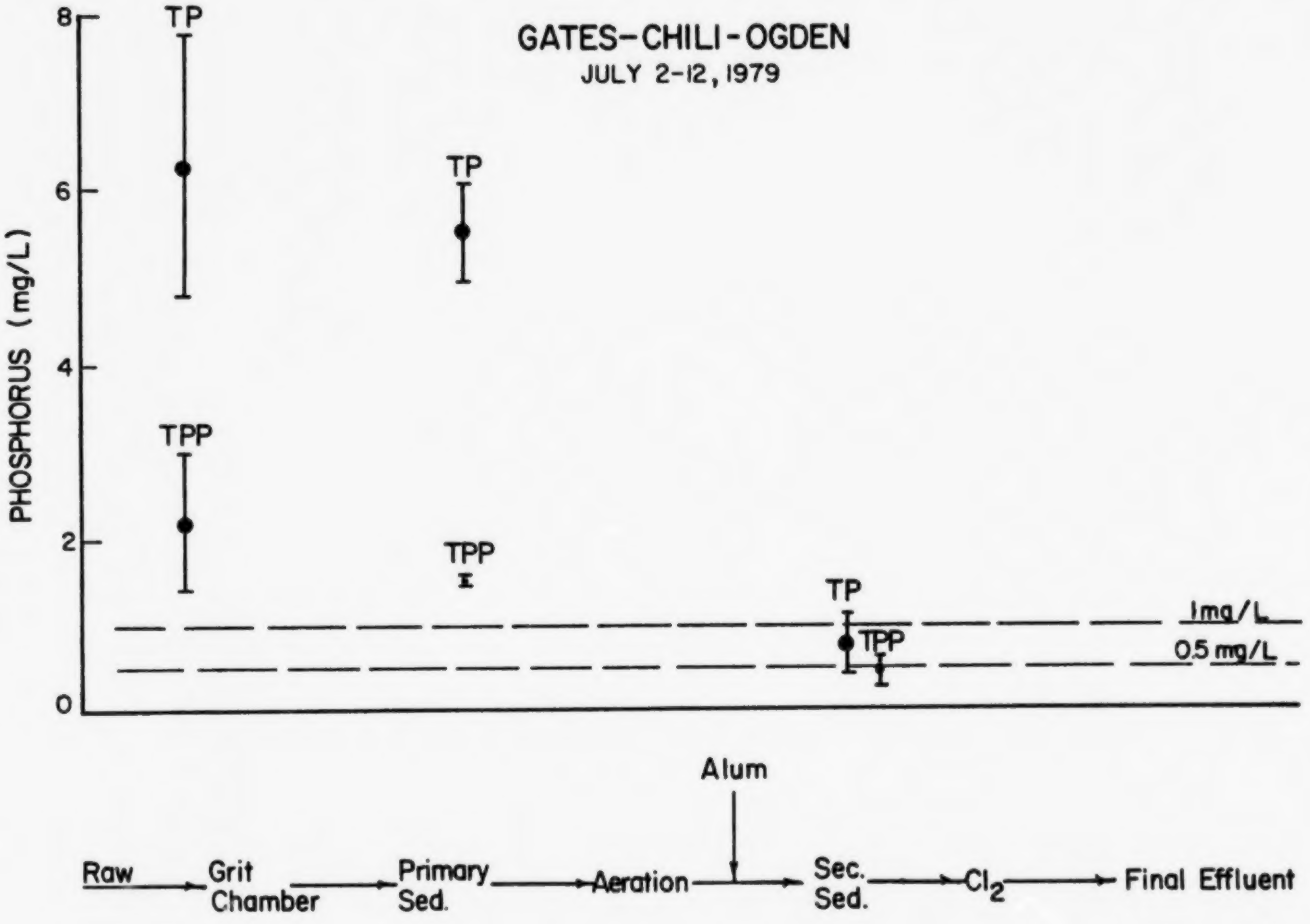

Figure 33. Summary of phosphorus data and line schematic - GCO

TABLE 24. GCO-TOTAL PLANT O&M COSTS

	Before P-Removal (Nov. 77-Apr. 78)		After P-Removal (Nov. 78-Apr. 79)	
	$/Year	$/1000 Gallons[1]	$/Year	$/1000 Gallons[1]
Labor	266,176	0.055	288,563	0.059
Power	281,723	0.057	304,971	0.064
Chemical	58,382	0.012	189,195	0.039
Miscellaneous	13,680	0.003	11,040	0.002
Total O&M	619,961	0.127	793,679	0.165

TABLE 25. GCO O&M COSTS FOR PHOSPHORUS REMOVAL (BASE PERIOD: NOV. 78 - APR. 79)

	$/Year	$/1000 Gallons
Labor	728	<.001
Power	101	<.001
Chemical	119,408	0.025
Total	120,237	0.026

[1] $/1000 gallons is equivalent to $/3.785 m^3

category. This can be used as an approximate means to account for inflation in comparing the two periods.

Table 25 presents a summary of operation and maintenance costs associated with phosphorus removal at GCO. Each item will now be explained. Labor costs associated with phosphorus are not very significant at GCO. When phosphorus removal was started, no additional personnel were hired. It is estimated that only two man-hours per week are allocated to the specific phosphorus removal practice. Using a rate of $7.00 per hour (from plant records) only $728 per year is spent.

Power costs were computed by determining the electricity required for operating the one-half horsepower (373 watts) motor for the alum feed pump. It was assumed that the pump is run continuously. An average rate of $0.031 per kilowatt hour is used for electrical costs which is the rate charged the GCO plant by Niagara Mohawk Power Co.

Finally, chemical costs were derived from actual costs incurred for liquid alum over the six month period, extrapolated to one year. The cost of the liquid alum was $0.059 per pound.

In examining the associated phosphorus removal costs it is evident that the item most sensitive to phosphorus removal is the chemical costs. Power and labor costs associated with phosphorus removal are not significant. Costs associated with the additional sludge generated from phosphorus removal are discussed in a later section.

Analysis of Performance

At the time of the sampling period at GCO, the alum was being added at a dosage of 70 mg/L. This corresponds to an Al^{+3} concentration of 3 mg/L. Based on the field data, an aluminum to phosphorus molar ratio can be calculated. Metal ion to phosphorus ratios, on both a total and soluble phosphorus basis, are listed for all four plants monitored in Table 26. Precipitation cation: soluble P dosage ratios are used in this report for calculation of sludge production associated with phosphorus removal. Ratios relative to total phosphorus are used in evaluating metal ion dosages and subsequent phosphorus removal.

Since at GCO the alum was added after the aeration basin, some of the 4 mg/L soluble phosphorus present in the raw waste was incorporated by biological synthesis into the mixed liquor biomass. Assuming a BOD:N:P ratio of 100:5:1 (uptake), approximately 1 mg/L of soluble P was removed by biological uptake. This left 3 mg/L of soluble P which could react with the aluminum. Accordingly, the phosphorus removal process at GCO was being operated at a dosage such that the Al:P ratio (soluble P basis) was 1.2. On the other hand, evaluation of the Al:P ratio on a total P basis yielded a value of 0.6, since the average primary effluent of total phosphorus was 5.5 mg/L. The typical pH of the secondary effluent was 7.4.

In addition to using the proper chemical and the proper dosage effective phosphorus removal requires adequate capacity in the solids

TABLE 26. PRECIPITATION CATION TO PHOSPHORUS RATIOS FOR THE PLANTS MONITORED

GCO

	Primary Effluent	Al:P (Molar)
Total P	5.5 mg/L	0.6
Soluble P	3.0 mg/L	1.2

Ely

	Primary Effluent	Al:P (Molar)
Total P	3.8	0.8
Soluble P	1.4	2.0

Big Sister Creek

	Secondary Sedimentation Effluent	Fe:P (Molar)
Total P	2.3	2.1
Soluble P	2.1	2.3

Van Lare

	Primary Influent	Al:P (Molar)
Total P	3.8	1.2
Soluble P	1.1	3.8

separation process in order to ensure a good removal of the precipitated phosphorus solids. A plot of phosphorus concentration versus overflow rates is shown in Figure 34, for the sampling period at GCO. As the process was operating at low overflow rates, there is no trend in the total particulate phosphorus concentration as a function of overflow rates. Figure 34 shows that for the period in which the sampling occurred, there was more than adequate clarification capacity. This is generally the case at GCO for most of the year.

Thus, the GCO plant was able to achieve good phosphorus effluent concentrations (average of 0.75 mg/L total P) by using moderate alum dosages with a conservative clarification capacity during our sampling period. GCO has in fact been easily meeting the average 1.0 mg/L effluent standard, based on monthly plant reports.

Alternatives to Meet a 0.5 mg/L Limit

Based on our field data, it is assumed that if a 0.5 mg/L effluent P standard were imposed at GCO, it could be met by increasing the alum dosage to a molar ratio of 1.5 (Al:P, on a soluble P basis). This would result in an increase in the alum dosage from 3 to 4 mg/L Al^{+3}. This assumes that sufficient clarification capacity would still be available. This assumption is critical to this alternative as most of the phosphorus remaining is most likely in a colloidal form, and the additional alum added would not be precipitating phosphorus, but rather coagulating the particulate forms. However, it should be pointed out that at the present time, two tertiary sedimentation basins exist at GCO which are not used. These were built for the initial phosphorus removal practice of tertiary lime precipitation which was abandoned at GCO in favor of alum precipitation in the secondary process due to economic considerations. Thus, additional clarification capacity would be available at no additional capital cost. It might also be necessary to add a polymer along with the alum for more effective particulate removal.

The incremental costs of going to 0.5 mg/L will be analyzed in terms of additional costs for chemicals and sludge processing. It is assumed that any additional power and labor costs directly associated with the actual phosphorus removal are negligible.

The additional chemical and sludge costs are shown in Table 27. The following assumptions were made in constructing Table 27. The alum dosage would be increased from 3 to 4 mg/L Al^{+3}; the unit cost of alum is \$0.059 per pound; the flows for chemical usage are the average six month flow of 13.3 mgd ($5x10^4$ m^3/day). The polymer dosage (if necessary) would be 1 mg/L at a unit cost of \$1.32 per pound (\$2.91/Kg). This is for the same polymer used by Monroe County Pure Waters at the Frank Van Lare plant. The quantities of total sludge generated at the plant are based on actual plant operations data corresponding to our sampling period. The unit cost of sludge processing (thickening, dewatering, and incineration) was \$71.37 per ton of dry solids processed. This figure was from actual plant records for the same time period. The flow used to compute actual sludge costs was that which has the average flow during the sampling period (9.5 mgd) ($3.6x10^4$ m^3/day). The amount of sludge generated from phosphorus removal was

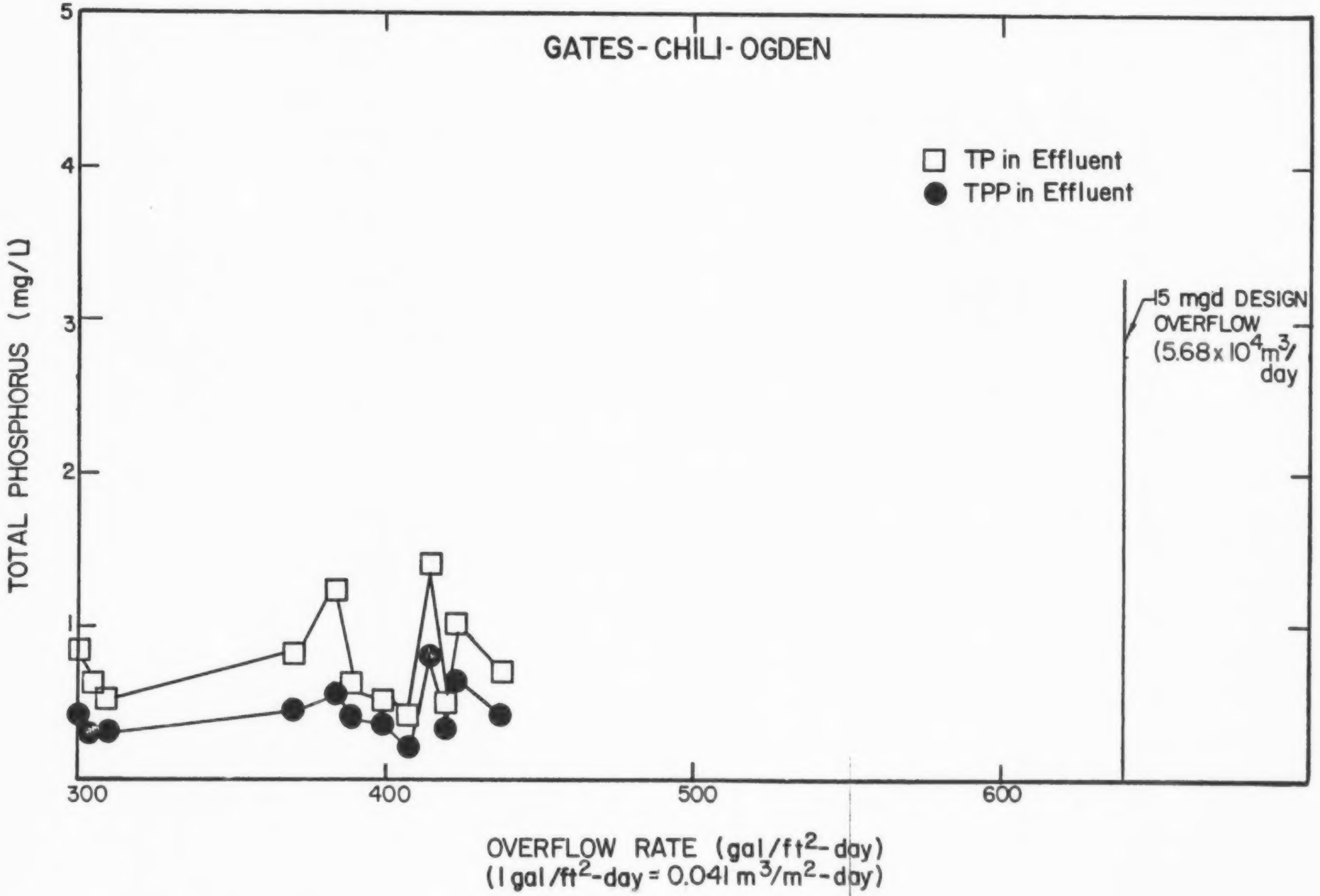

Figure 34. Phosphorus concentration of second effluent versus overflow rate of final sedimentation basin - GCO

TABLE 27. SLUDGE AND CHEMICAL COSTS AT GCO (SUMMER 1979)

	Chemical Costs $/1000 Gallons	P Sludge[2] lbs/10^6 gals	Total Sludge lbs/10^6 gals	P Sludge Cost $/1000 Gallons
Present Conditions 0.75 mg P/L	0.025	120	1387	0.004
0.5 mg P/L (alum alone)	0.030	140	1527	0.005
0.5 mg P/L (alum with polymer)	0.040	140	1527	0.005

TABLE 28. SUMMARY OF INCREMENTAL COST AT GCO FOR ACHIEVING A 0.5 mg P/L RESIDUAL

Category	$/Year	$/1000 Gallons
Sludge Processing	2080	0.001
Chemical (alum alone)	24,364	0.005
Chemical (alum & polymer)	79,039	0.016

[1] $/1000 gallons is equivalent to $/3.785 m^3

[2] lbs/10^6 gallons is equivalent to 0.12 g/m^3

calculated by stoichiometric relationships between aluminum ion and soluble phosphorus and hydroxide as described by Vesilind (1979).

Finally, the costs of sludge processing attributed to phosphorus removal were computed by multiplying the amount of P sludge by the unit cost of sludge processing. This technique is somewhat liberal in that the alum sludge generated from phosphorus removal is more difficult to thicken and dewater than the mixture of primary or secondary sludge. However, it should be noted that it is only a small percentage of the total amount of sludge generated at GCO.

The incremental costs for achieveing a 0.5 mg/L standard are summarized in Table 28. Several points should be noticed. First of all, the incremental sludge costs is not very significant in terms of the overall O&M costs. However, additional examination of the GCO plant would have to be made in order to determine if adequate thickening, pumping, and dewatering facilities exist for processing the additional sludge. Such a complete type of analysis was beyond the scope of this study.

The additional alum cost would result in a 20 percent increase in chemical costs. If polymer were needed, the increase would be 66 percent. These represent significant increases.

For GCO the phosphorus data indicate that an 0.5 mg/L P effluent limitation could be met without tertiary filtration. However, we have computed the costs if GCO were required to add filtration. For a 20 mgd (7.5×10^4 m^3/day) plant, such as GCO, the capital costs for filtration are estimated to be \$$2.84 \times 10^6$ (2nd Quarter, 1979) (EPA, 1978a), while the annual O&M costs would be \$290,000 (August, 1979) (Weston, 1977).

ELY

Introduction

A description of the Ely, Minnesota wastewater treatment plant and the field data collected there have been presented previously (Section 6). A summary of the phosphorus data and a line schematic diagram of the processes employed are shown in Figure 35.

The U.S. Environmental Protection Agency (EPA) in cooperation with the City of Ely, funded construction of an advanced wastewater treatment facility to demonstrate that a reduction in phosphorus from a point source could improve the trophic status of Shagawa Lake. Prior to the construction of the tertiary plant, the Ely waste treatment facility consisted of a conventional secondary treatment operation. The tertiary plant began operation in the spring of 1973. It was designed and constructed as a research facility with very high phosphorus removal efficiency (to limit the phosphorus content of the effluent to 0.05 mg/L or less (EPA, 1978b)).

Originally during the demonstration, phosphorus removal was practiced by lime precipitation in the tertiary solids contact tanks. After the demonstration was finished the plant switched to $FeCl_3$ precipitation of

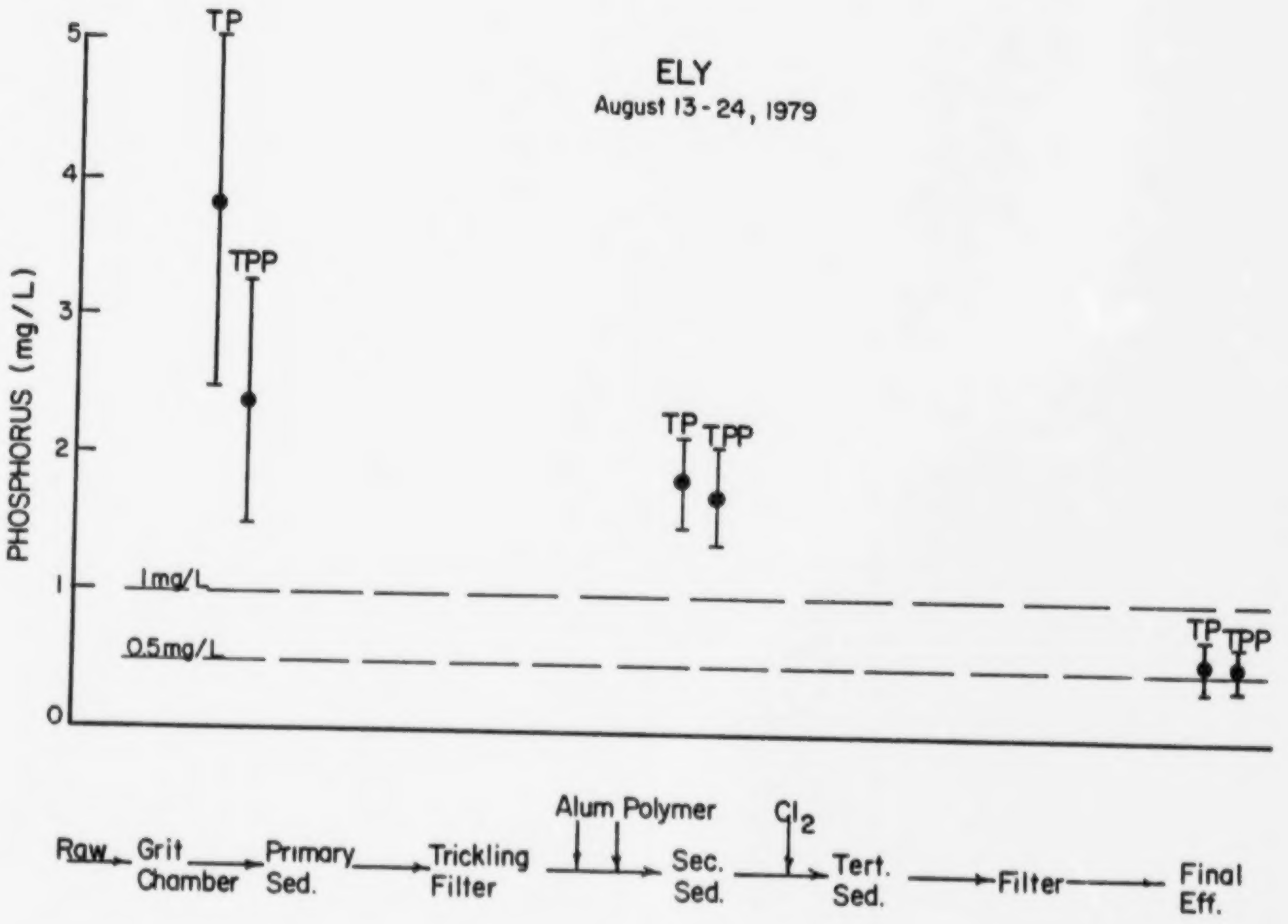

Figure 35. Summary of phosphorus data and line schematic - Ely

phosphorus from the trickling filter effluent. Beginning in June, 1979 the plant switched to liquid alum and polymer addition to the trickling filter effluent followed by secondary settling and tertiary filtration. This was the phosphorus removal practice used during the field sampling of this project.

The liquid alum used for phosphorus removal was a 48 percent alum solution. During the field sampling the dosage varied between 50 and 60 mg/L. The polymer added to the trickling filter effluent was Betz 1160, a cationic polymer. It was added at a concentration of 0.3 mg/L.

Operation and Maintenance Costs

Total operation and maintenance costs for Ely are presented in Table 29. These costs are based on the three month period of actual plant records from June through August of 1979, extrapolated to one year. Prior to June, phosphorus removal was practiced by $FeCl_3$ addition; therefore, the months of January through May were not used. Fuel costs were not available for this three month period; hence, 1978 figures were used for that portion of the power costs.

Table 29 shows the amount of money spent at Ely for wastewater treatment (\$0.916/1000 gallons) (\$0.24/m^3) and that most of this cost is associated with labor (\$0.680/1000 gallons) (\$0.18/m^3). This is primarily due to the fact that the City of Ely has a contract from the EPA to run this plant which was built as a research facility. At the present time, a consulting engineering company is operating the plant for the City of Ely. Thus, the O&M costs are distorted by labor and overhead costs which are not typical for a treatment plant of this size (approximately 1 mgd, 3.785×10^3 m^3/day).

Table 30 presents a summary of operation and maintenance costs associated with phosphorus removal at Ely. Labor costs associated with phosphorus removal are computed by allocating 40 hours of manpower per week. This assumption is based on the judgment of the plant supervisor at Ely. Using a rate of \$6.00 per hour and 52 weeks per year, the labor costs associated with phosphorus removal are thus \$12,480 per year. Power costs were computed by actual horsepower requirements for tertiary wastewater pumping (15 HP) (11.2 kilowatts), polymer and alum pumping (0.5 HP each) (373 watts) and an air scour were operated for 20 minutes each day. A rate of \$0.06 per kilowatt hour is used for calculating the electrical cost, based on actual service charges at the Ely plant. Chemical costs are based on the 3 month costs for the liquid alum and polymer, and extrapolated to one year.

Sludge production associated with phosphorus removal is shown in Table 31. The chemical dosages are based on average dosages used during the field sampling at Ely. Total sludge production is based on actual plant data during the sampling period. The sludge associated with phosphorus removal was calculated by the stoichiometric relationship between the aluminum ion and soluble phosphorus and hydroxide ion as described by Vesilind (1979). Additional particulate phosphorus sludge removed by filtration is also included.

TABLE 29. ELY – TOTAL PLANT O&M COSTS
(TIME PERIOD BASIS: SUMMER 1979)

	$/Year	$/1000 Gallons[1]
Labor	223,200	0.680
Power	33,421	0.102
Chemical	24,648	0.075
Miscellaneous	19,525	0.059
Total O&M	300,794	0.916

TABLE 30. ASSOCIATED O&M COSTS FOR PHOSPHORUS REMOVAL – ELY

	$/Year	$/1000 Gallons
Labor	12,480	0.038
Power	6,325	0.019
Chemical	16,501	0.050
Total	35,296	0.107

TABLE 31. ELY SLUDGE PRODUCTION AND CHEMICAL
DOSAGES FOR P REMOVAL

Chemicals[2] lbs Alum/10^6 gals	lbs Polymer/10^6 gals	P Sludge[2] lbs/10^6 gals	Total Sludge lbs/10^6 gals
487	2.84	82.45	3415

[1] $/1000 gallons is equivalent to $/3.785 m^3

[2] lbs/10^6 gallons is equivalent to 0.12 g/m^3

The unit cost of solids processing could not be determined for Ely due to lack of sufficient plant data, in that separate solids and liquid treatment portions of the total cost were not maintained by the plant operators. However, it can be seen that only a small percentage of the total sludge generated is associated with phosphorus removal.

Analysis of Performance

The Ely wastewater treatment plant has a phosphorus effluent standard of 0.4 mg/L. During the time of the field sampling, liquid alum was added to the trickling filter effluent at an average dosage of 58 mg/L which is equivalent to an aluminum ion concentration of 2.5 mg/L Al^{+3}. This resulted in an Al:P ratio of 0.8 on a total P basis. The average soluble phosphorus concentration coming into the trickling filter was 1.4 mg/L. This results in a Al:P molar ratio of 2.0 (soluble basis) not accounting for the soluble phosphorus which was removed by biological uptake in the trickling filter. If this were taken into account, assuming 1 mg/L soluble phosphorus taken up for every 100 mg/L BOD removed, the soluble phosphorus concentration at the point of liquid alum addition would be 0.5 mg/L and the Al:P would be 5.5. By either basis, a sufficiently high dose of liquid alum is applied to the trickling filter effluent. Examination of Figure 35 verifies that almost all of the phosphorus in the secondary sedimentation effluent is in a particulate form, therefore the dosage used is precipitating the phosphorus. The pH of the secondary effluent during the sampling period was typically 7.3.

At Ely, a trickling filter plant, it is clear that the 0.4 mg/L effluent standard can not be met with chemical addition alone. While the phosphorus was successfully insolubilized by the alum addition, it was not effecitvely removed in secondary sedimentation. This may be due to the nature of the settling of the solids which slough off trickling filters as opposed to the zone settling phenomenon associated with activated sludge biomass which may better capture the particulate phosphrous. At any rate, the concentration of suspended solids in the secondary clarifier effluent was 58 mg/L.

Figure 36 shows the results of a jar test conducted on the trickling filter effluent. It can be seen that the plant dosage used, indicated by the arrow, does result in a low soluble phosphorus concentration. The phosphorus is in a non-settleable particulate form and the jar tests data show additional alum is required, approximately 3 times more to coagulate the particulate phosphorus. Note that the data for an alum dosage of zero are for a control and do not match the initial data as settling had occurred in the jar test beakers. Although the Ely plant uses a cationic polymer dosage of 0.3 mg/L, no jar tests were conducted with the polymer. If the pH were adjusted to 6.0, a more optimal pH for phosphorus precipitation with aluminum, it would produce little difference in the results. This is shown in Figure 37. For these tests, alum was added to the samples and then the pH was adjusted to 6.0. These results indicate that additional alum is required for coagulation to achieve solid separation.

A plot of the total phosphorus concentration in the secondary effluent versus overflow rate is shown in Figure 38. The secondary sedimentation

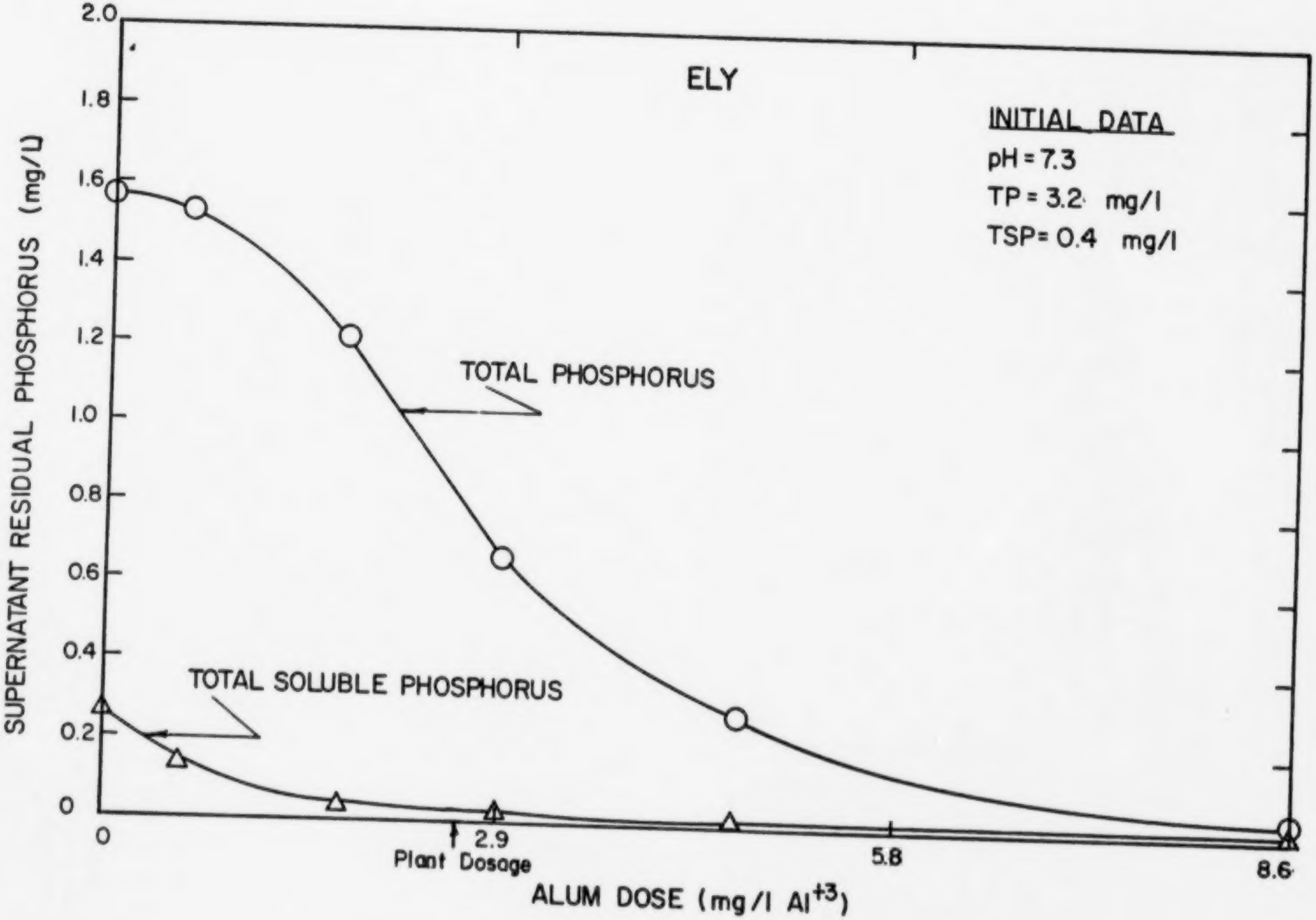

Figure 36. Jar test results (unadjusted pH) - Ely

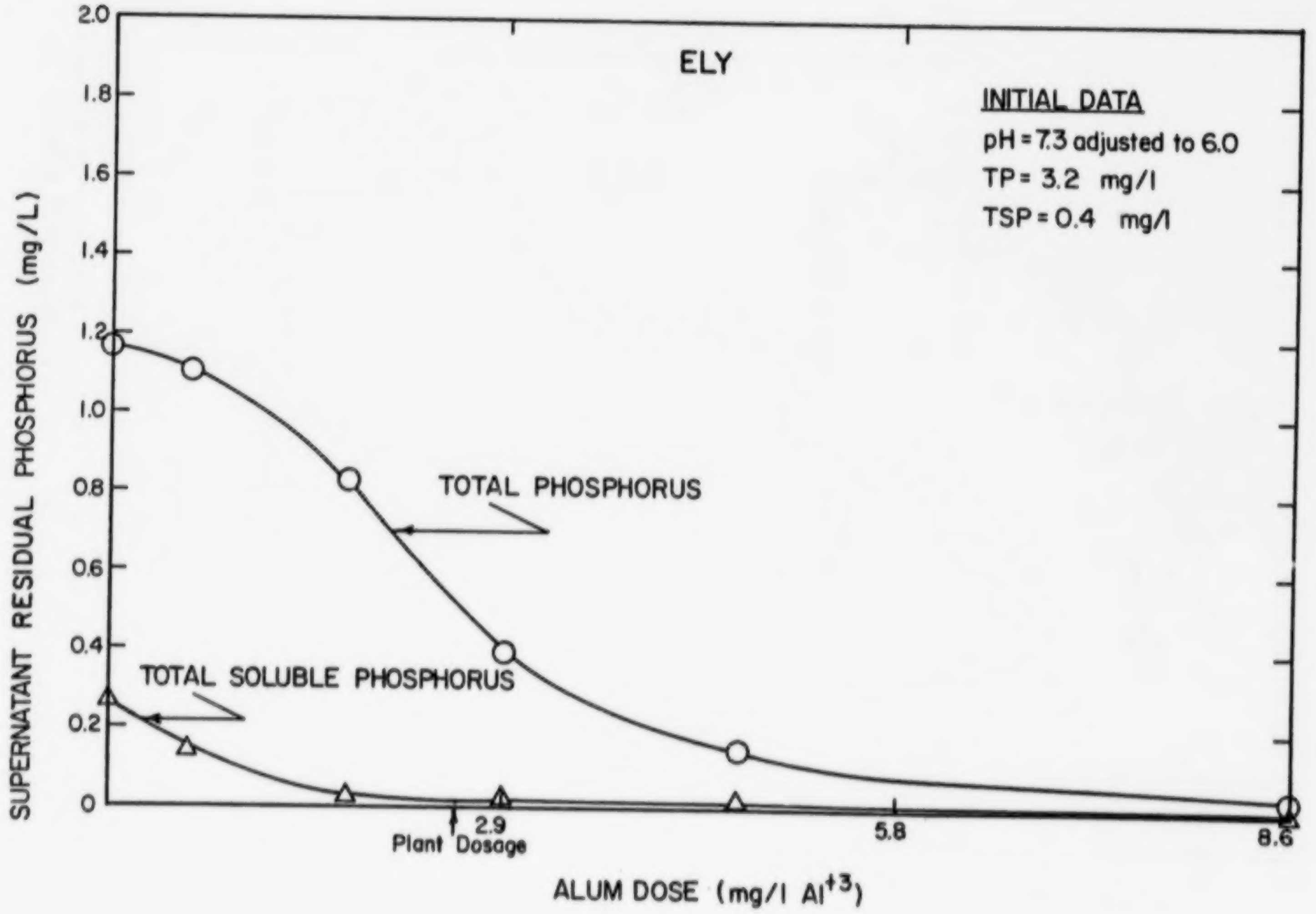

Figure 37. Jar test results (pH adjusted to 6) - Ely

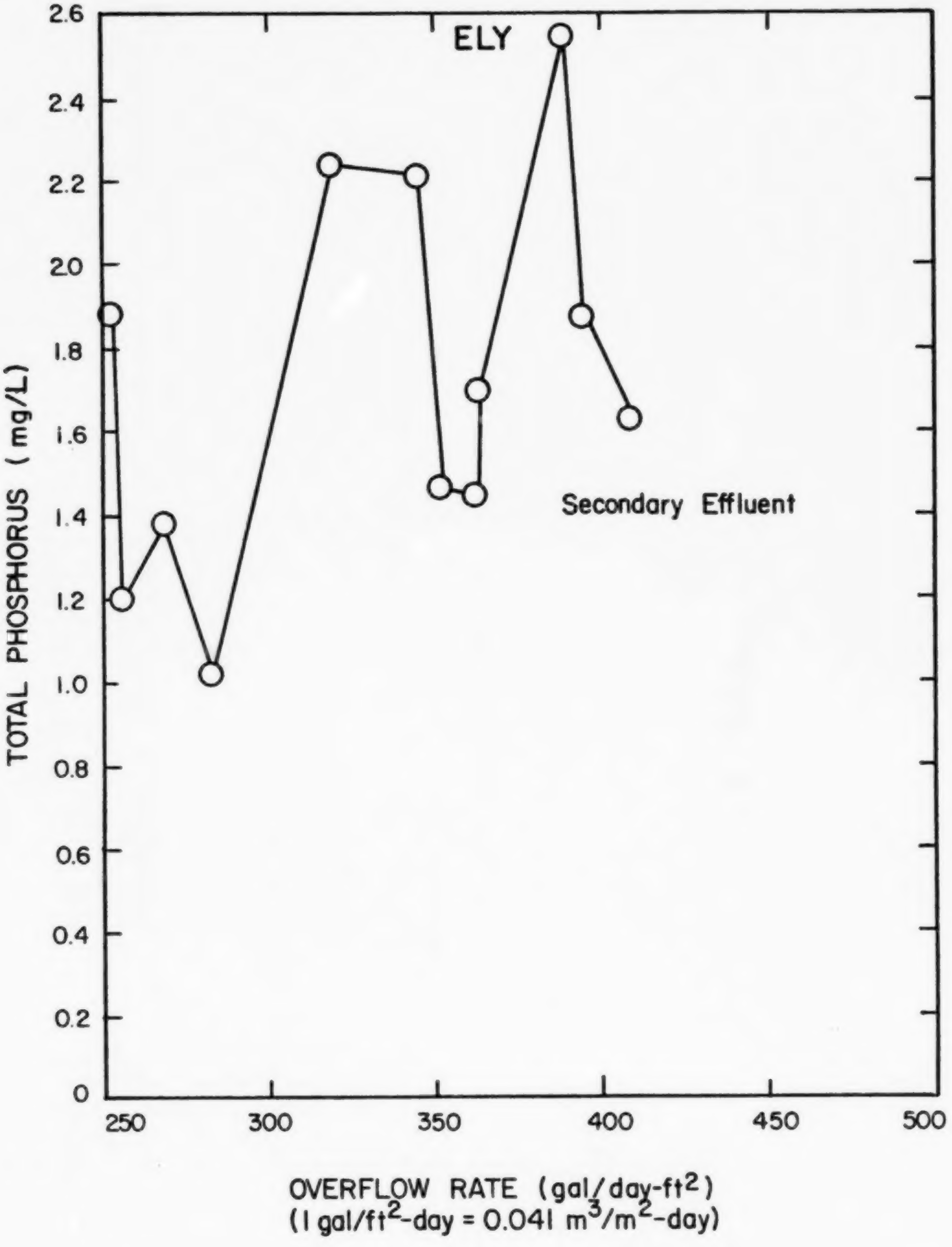

Figure 38. Phosphorus concentration of secondary effluent versus overflow rate of secondary sedimentation basin - Ely

basin is designed for an overflow rate of 765 gallons per day per square foot (31.4 m^3/m^2/day) at a flow of 1.5 mgd (5.7×10^3 m^3/day). It can be seen that even at the low overflow rates observed during the field sampling, the phosphorus did not settle out well, as most of the phosphorus is particulate (see Figure 35). Therefore filtration is needed to approach the 0.4 mg/L standard at Ely.

The filtration unit at Ely is a dual media filter consisting of two feet (61 cm) of anthracite on top of one foot (30.5 cm) of sand. It is backwashed for 20 minutes each day. The data shown in Figure 39 indicate that the filter removes about 65 percent of the particulate phosphorus. Improvement in particulate phosphorus removal might be achieved by using a filter aid.

BIG SISTER CREEK (ANGOLA, NEW YORK)

Introduction

The Big Sister Creek wastewater treatment plant located near Angola, NY is a 3.1 mgd (1.1×10^4 m^3/day) tertiary plant. A description of the Big Sister Creek wastewater plant and field data collected there have been presented previously (Section 6). A summary of the phosphorus data and a line schematic diagram of the processes employed are shown in Figure 40.

Phosphorus removal has been practiced at Big Sister Creek since May, 1977. It is removed during tertiary treatment by the addition of $FeCl_3$ and a polymer to 70 percent of the secondary effluent. The secondary treatment process is activated sludge operated in an extended aeration mode. Tertiary processes include solids-contact clarifiers and filtration through a gravity sand filter. The plant has a phosphorus effluent standard of 1.0 mg/L.

The $FeCl_3$ added for phosphorus removal was added at a concentration of 25 mg/L, which is equivalent to 8.7 mg/L of Fe^{+3}, during the sampling period at Big Sister Creek. It must be noted, however, that this dosage varied widely throughout the year. During a three month period of December 1977 through February 1979 no $FeCl_3$ was needed for phosphorus removal as effluent standards could be met without the addition of chemicals. The plant serves a resort area and thus flows are higher during the summer. In addition to $FeCl_3$, Hercules 847 (an anionic polymer) was also used at a dosage of 0.6 mg/L.

Operation and Maintenance Costs

Total operation and maintenance costs for Big Sister Creek are presented in Table 32. These costs are taken from actual plant records from 1978. Table 33 presents a summary of operation and maintenance costs associated with phosphorus removal at Big Sister Creek. Labor costs associated with phosphorus were based on the allocation of manpower by the plant supervisor. The total man-hours at Big Sister Creek during 1978 was 14,298 hours. Of this, 1653 man-hours were allocated to operation of the filter (12 percent) and 1835 hours were allocated to the solids contact clarifier (13 percent). Power costs were assigned by actual horsepower data for each process. Fifty-

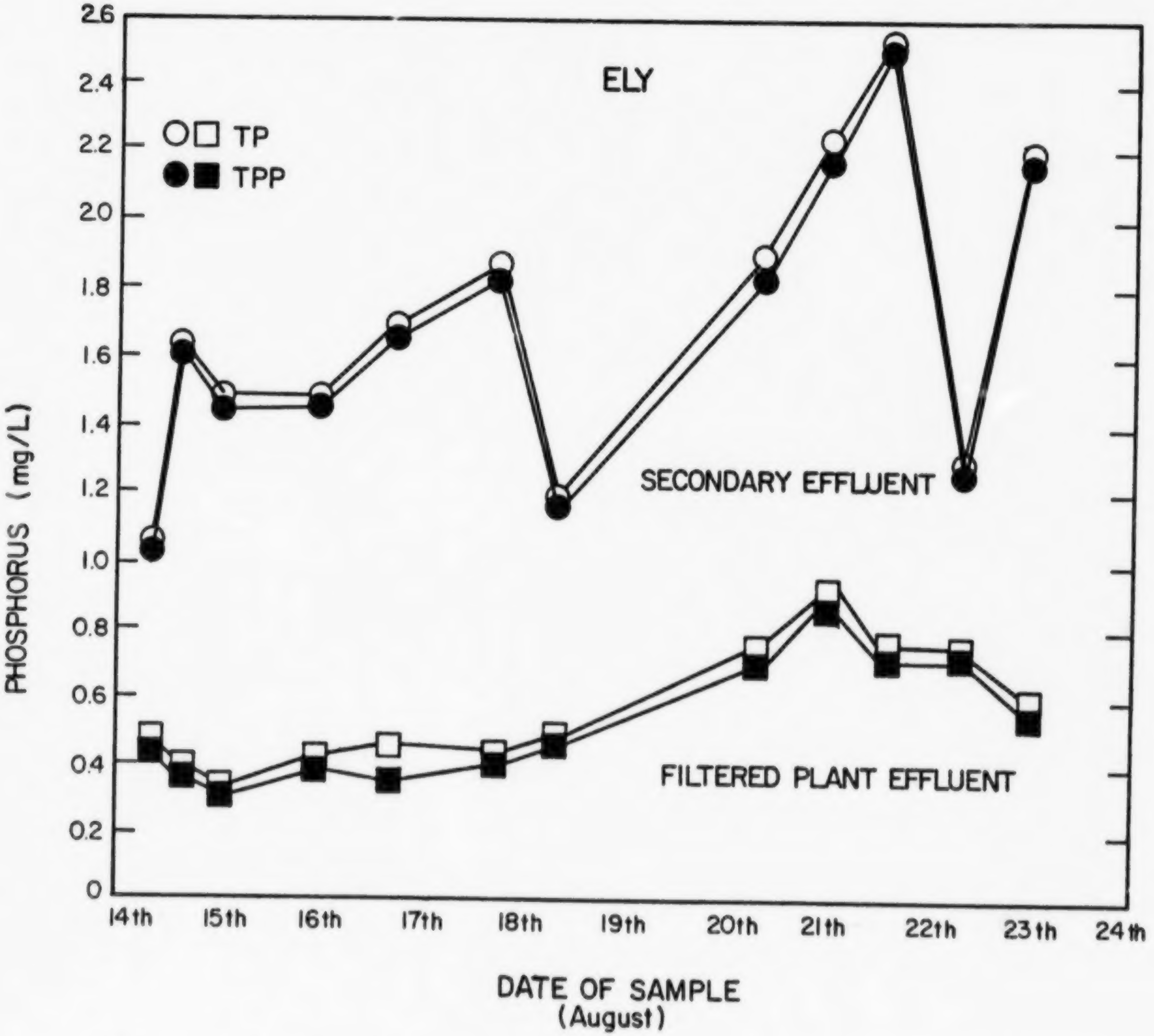

Figure 39. Secondary effluent and dual media filtered effluent phosphorus concentrations - Ely

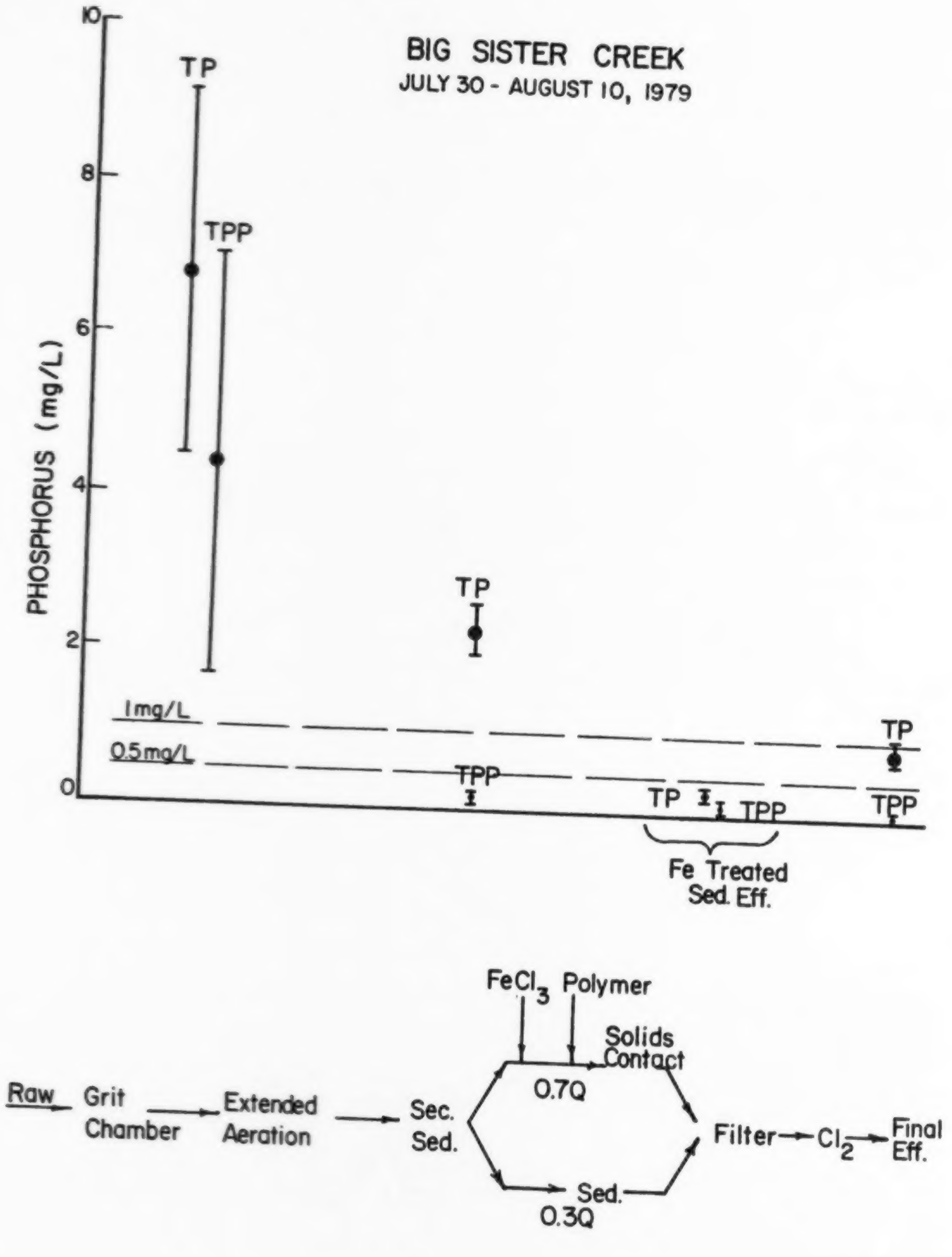

Figure 40. Summary of phosphorus data and line schematic - Big Sister Creek

TABLE 32. BIG SISTER CREEK - TOTAL PLANT O&M COSTS (1978)

	\$/Year	\$/1000 Gallons[1]
Labor	258,384	0.228
Power	99,301	0.088
Chemical	16,983	0.015
Miscellaneous·	45,994	0.041
Total O&M	420,662	0.372

·Includes such things as telephone service and water

TABLE 33. ASSOCIATED O&M COSTS FOR PHOSPHORUS REMOVAL – BIG SISTER CREEK

	\$/Year	\$/1000 Gallons
Labor	91,133	0.081
Power	4,834	0.004
Chemical	12,501	0.011
Total	108,468	0.096

TABLE 34. BIG SISTER CREEK SLUDGE PRODUCTION AND CHEMICAL DOSAGES FOR P REMOVAL

Chemicals[2] - lbs/10^6 gals		P Sludge[2] lbs/10^6 gals	Total Sludge lbs/10^6 gals	P Sludge Cost \$/1000 Gallons
$FeCl_3$	Polymer			
149[3]	3.29[4]	116	990	0.013

[1] \$/1000 gallons is equivalent to \$/3.785 m^3

[2] lbs/10^6 gallons is equivalent to 0.12 g/m^3

[3] given for total plant flow; is equal to 212.8 lbs/10^6g for treated flow

[4] given for total plant flow; is equal to 4.7 lbs/10^6g for treated flow

two percent of the power costs were due to the solids contact clarifier and associated equipment, while 48 percent were due to the filter. Chemical costs were computed based on the dosages and flow (2.58 mgd, 9.8×10^3 m^3/day) during the sampling period extrapolated to a nine month period, as chemical addition for phosphorus removal is not necessary year round at Big Sister Creek. This estimate is on the high side as smaller dosages can be used during much of the year due to seasonal variation in wastewater composition.

Sludge production associated with phosphorus removal is shown in Table 34. The chemical and polymer quantities are based on quantities used during the field study and are based on a total flow (2.58 mgd, 9.8×10^3 m^3/day). The sludge associated with phosphorus removal was calculated based on stoichiometry (Vesilind, 1979). The total quantity of sludge produced is from plant records, for the sampling period. The costs associated with phosphorus sludge processing is based on a unit cost of $223 per ton of dry solids processed. Again, this unit cost would be on the liberal side as the iron-phosphorus sludge would be more difficult to process than the mixture of primary, secondary, and chemical sludges on which the $223 figure is based.

Analysis of Performance

At the time of the sampling period at Big Sister Creek, the $FeCl_3$ was being added at a dosage of 8.7 mg/L Fe^{+3}. The polymer was added at a dosage of 0.6 mg/L. Based on the field data an iron to phosphorus ratio can be calculated. On a total P basis, the ratio was 2.1. Soluble phosphorus in the secondary effluent averaged 2.1 mg/L. This results in an Fe:P molar ratio of 2.3 (soluble basis). Jar test results for the secondary effluent are shown in Figure 41. Both the field data (Figure 40) and jar test data indicate that the Fe dosage is adequate in both insolubilizing the phosphorus and removing it by sedimentation. In fact, the data show that a total phosphorus of less than 0.5 mg/L can be achieved. The pH of the secondary effluent during the sampling period was typically 7.4.

A large fraction of the particulate phosphorus was removed during the extended aeration process with subsequent settling. The secondary sedimentation basin is conservatively designed with an overflow rate of 500 gallons per day per square foot (20.5 m^3/m^2/day). This partially accounts for the high degree of particulate phosphorus removal. In examining Figure 41, which shows total and particulate phosphorus concentration of secondary and solids contact effluents versus overflow rate, it can be seen that the 0.5 mg/L phosphorus effluent limitation can be met without filtration. Also from Figure 42, it appears that an overflow rate of 550 gpd/ft^2 (22.6 m^3/m^2/day) and less produced similar results. These data demonstrated the good efficiency of Fe in insolubilizing the phosphorus. Both the secondary and solids contact units were designed at overflow rate of 500 gpd/ft^2 (20.5 m^3/m^2/day) at a design flow of 22 mgd (8.3×10^3 m^3/day). It should be pointed out that because of the many variables associated with actual performance, it would take significantly more data to show the effect of overflow rate on effluent quality.

A plot of filter performance at Big Sister Creek is shown in Figure 43. The filter used at Big Sister Creek consisted of 12 inches (30.5 cm) of high

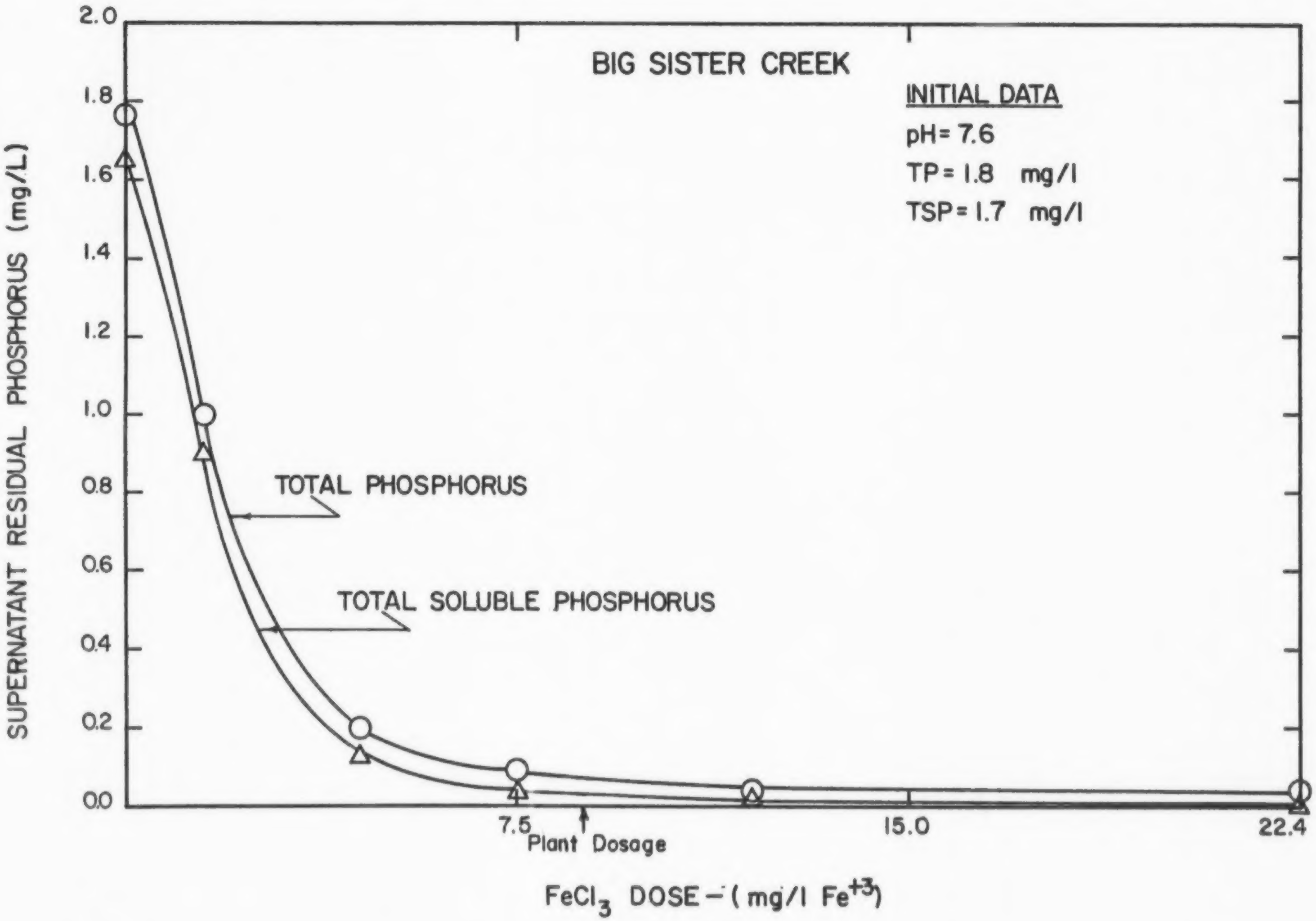

Figure 41. Jar test results - Big Sister Creek

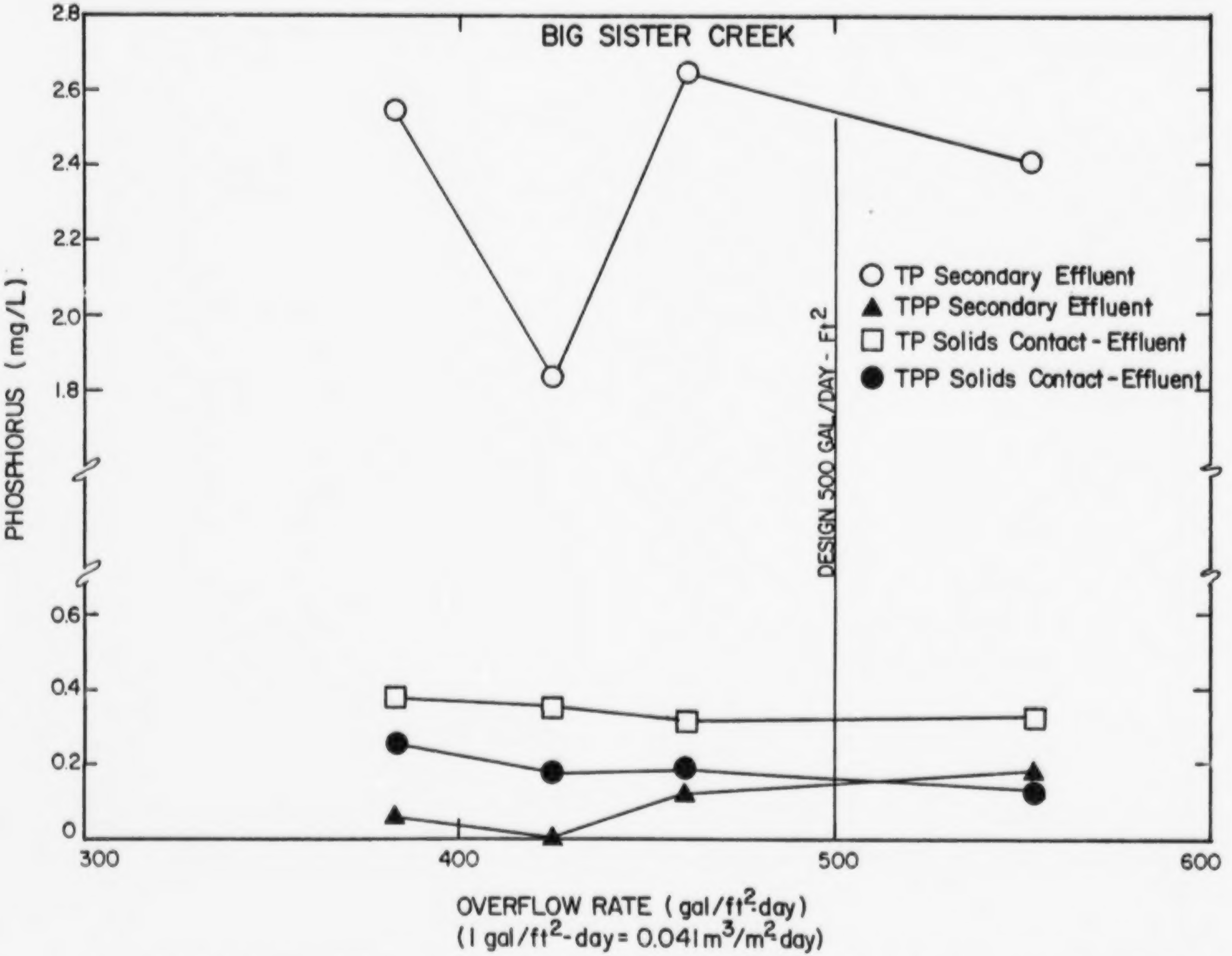

Figure 42. Phosphorus concentrations of secondary and solids contact effluents versus overflow rate - Big Sister Creek

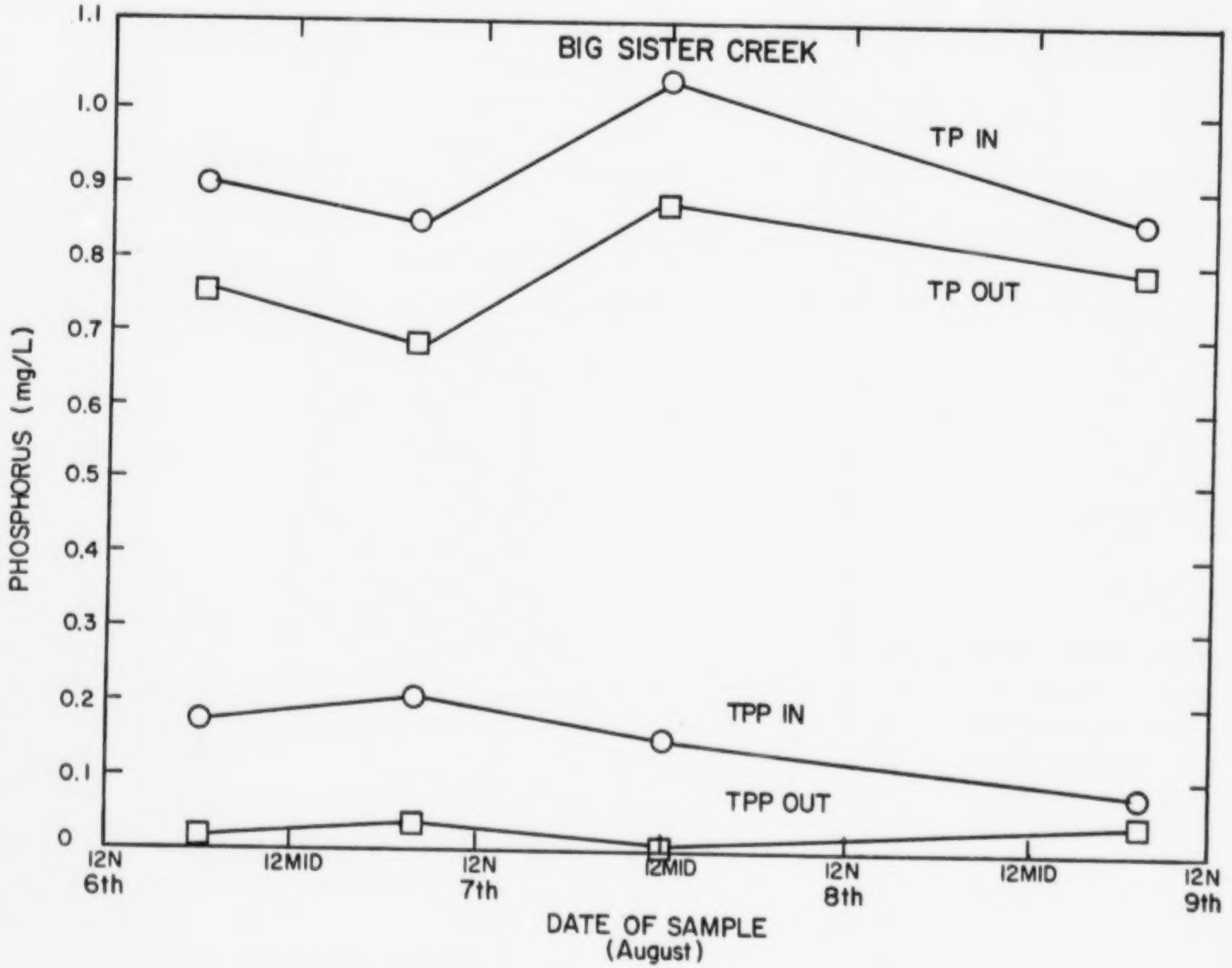

Figure 43. Granular media filter performance - Big Sister Creek

grade silica with a uniformity coefficient of 1.3 - 1.5 and an effective size of 0.55 - 0.65 mm. Figure 42 clearly shows that the filter was a polishing operation at the wastewater plant. Most of the phosphorus going to the filter is soluble, less than 0.2 mg/L is particulate. The major purpose it serves now is as a protective measure against solids blowout of the solids contact units during periods of excessive flow.

Alternatives to Meet a 0.5 mg/L Limit

Based on the results of the jar tests and field data, if a 0.5 mg/L effluent standard were imposed at Big Sister Creek, it could be met by treating all the flow, rather than the present 70 percent, at the same dosages of $FeCl_3$ and polymer. This would result in an increase in chemical costs of $5357 per year and in the generation of 50 extra pounds (23 Kg) of sludge per million gallons treated which would result in an incremental sludge handling cost of $3959 per year. These costs are based on a flow of 2.58 mgd (9.8×10^3 m^3/day) for 9 months of the year. It is assumed that no additional power or labor costs would occur.

FRANK VAN LARE

Introduction

The Frank Van Lare wastewater treatment plant is located in Rochester, NY. It has an average daily flow of approximately 100 mgd (3.78×10^5 m^3/day). A description of the Van Lare plant and the field data collected there have been presented previously (Section 6). A summary of the phosphorus data and a line schematic drawing of the processes employed are shown in Figure 44. The Van Lare plant (along with GCO) is operated by the Division of Pure Waters of Monroe County.

The Van Lare plant was upgraded several years ago from a primary to a secondary treatment facility. As part of this upgrading, phosphorus removal was included. The original method of phosphorus removal at Van Lare after upgrading involved lime addition to the primary settling tanks with provision for recovery of lime. This method was used only for a brief time at Van Lare and then abandoned due to excessive sludge production.

Beginning in 1979, phosphorus removal was again practiced at Van Lare with liquid alum and a polymer being added to a portion of the flow in the primary sedimentation basins. Due to the industrial input to the wastewater at Van Lare, the waste is generally nutrient deficient and hence an effluent concentration approaching 1 mg/L can be produced by means of conventional secondary treatment. In order to meet a level of 1 mg/L the operators began treating increasing increments of the raw wastewater in the primary tanks, until the present portion which is 20 percent of the flow was found to be sufficient.

Thus, at present 20 percent of the incoming flow is treated in one of the primary settling basins on the east side (referred to in Figure 44 as the Chemical Side) of the plant and then mixed with the other 80 percent of the flow after secondary settling. In other words, the 20 percent treated

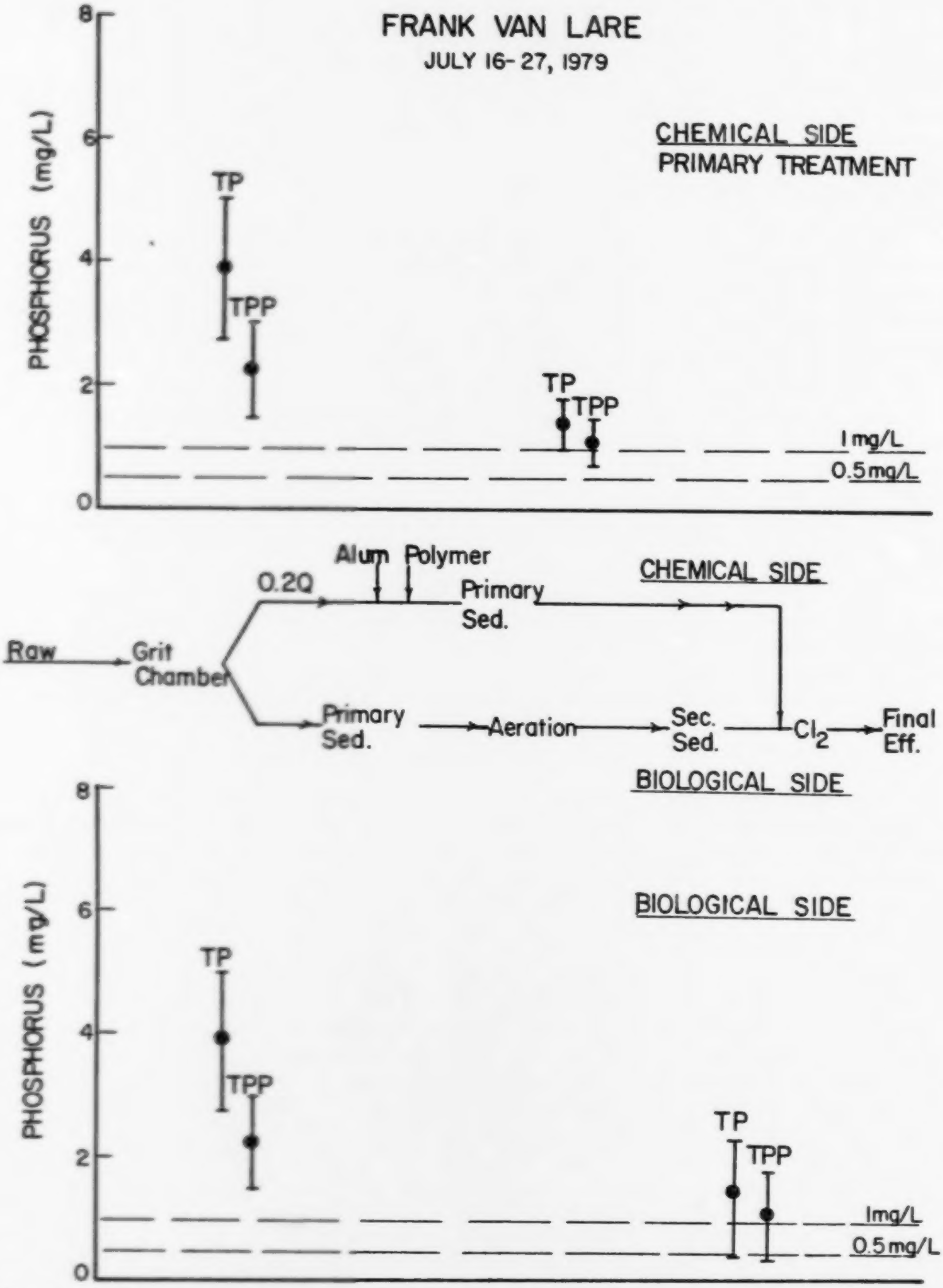

Figure 44. Summary of phosphorus data and line schematic - Frank Van Lare

with liquid alum and polymer does not undergo biological treatment, in this case the activated sludge process.

The liquid alum used at Van Lare is a 48 percent alum solution purchased from Allied Chemical. During the sampling period, a dosage of 85 mg/L was used which is equivalent to 3.2 mg/L of Al^{+3}. The polymer used was Carborundum WT 3000, which was used at a dosage of 0.4 mg/L.

Operation and Maintenance Costs

Total operation and maintenance costs for Van Lare are presented in Table 35. Note that two periods are shown — one corresponding to a time when phosphorus removal was not being practiced and one when phosphorus removal was practiced. Each of these is based on five months of actual plant records extrapolated to a one year period. These costs are reported in dollars of their respective periods and are therefore not indexed. Based on the Consumer Price Index for all urban consumers (CIP-U) (Department of Labor, 1979), the rate of increase was 11.8 percent for August 1978 to August 1979 (unadjusted) for all items in the CPI expenditure category. This can be used as an approximate means to account for inflation in comparing the two periods. The extremely high power costs listed in Table 35 are mostly due to sludge incineration which is supplemented with oil.

Table 36 presents a summary of operation and maintenance costs associated with phosphorus removal at Van Lare. Labor costs associated with phosphorus removal are not very significant. As is the case at the GCO plant when phosphorus removal was started, no additional personnel were hired. It is estimated that only two man-hours per week are allocated to phosphorus removal. Specifically, using a rate of $7.00 per hour (from plant records) only $728 per year is spent.

The power costs directly associated with phosphorus removal are also insignificant. They were computed by converting electrical requirements for pumping the alum and polymer to the primary sedimentation basins. Both are pumped by 1/2 HP (373 watts) motors and it is assumed that both are operated continuously. An average rate of $0.029 per killowatt hour was used, which was obtained from actual plant records. Although both Van Lare and GCO are in the same area (Rochester), Van Lare being a larger consumer of electricity is charged a lower rate by the power company.

Finally, chemical costs were derived from actual costs incurred for liquid alum and the polymer over the five months period extrapolated to one year. The total includes $233,141 for alum and $27,532 for polymer. As was the case with GCO, the chemical costs are the most significant item in terms of phosphorus removal costs.

Table 37 shows cost associated with the additional sludge generated from phosphorus removal. The alum and polymer quantities are based on actual dosages used during the field study. The sludge associated with phosphorus removal was calculated based on the stoichiometric relationship of Al^{+3} to soluble phosphorus (Vesilind, 1979). It also includes the addition of suspended solids removed in primary sedimentation due to alum. The total

TABLE 35. VAN LARE - TOTAL PLANT O&M COSTS

	Before Phosphorus Removal (Feb-June 1978)		After Phosphorus Removal (Feb-June 1979)	
	$/Year	$/1000 Gallons[1]	$/Year	$/1000 Gallons
Labor	613,113	0.021	756,226	0.020
Power	2,090,599	0.071	2,934,250	0.079
Chemical	334,035	0.011	819,655	0.022
Miscellaneous	68,737	0.002	7,560	0.002
Total O&M	3,106,484	0.105	4,517,691	0.123

TABLE 36. ASSOCIATED O&M COSTS FOR PHOSPHORUS REMOVAL - VAN LARE

	$/Year	$/1000 Gallons
Labor	728	0.0001
Power	190	0.0001
Chemical	260,674	0.007
Total	261,592	0.007

TABLE 37. VAN LARE SLUDGE PRODUCTION AND CHEMICAL DOSAGES FOR P REMOVAL (BASE PERIOD: SUMMER, 1979)

Chemicals - Alum	Polymer[2] lbs/10^6 gals	P Sludge[2] lbs/10^6gals	Total Sludge lbs/10^6 gals	P Sludge Cost $/1000 Gallons
141.7	0.684	252	1529	0.004

[1] /$/1000 gallons is equivalent to $/3.785 m^3

[2] lbs/10^6 gallons is equivalent to 0.12 g/m^3

quantity of sludge produced is from plant records for the sampling period. The costs associated with phosphorus sludge processing is based on a unit cost of $158 per ton of dry solids, taken from plant records during the sampling period. Again this unit cost would be on the liberal side as the alum sludge would be more difficult to process than the mixture of primary and secondary and alum sludge on which the $158 figure is based.

Analysis of Performance

The Van Lare wastewater treatment plant which discharges directly into Lake Ontario has an effluent standard of 1.0 mg/L. The wastewater which enters the plant is generally low in total phosphorus averaging 3.8 mg/L during the field sampling. This is mainly due to the phosphorus ban on detergents in New York State and a large industrial input which is low in phosphorus. Becuase of this, a low effluent phosphorus level can be achieved through conventional primary sedimentation and the activated sludge process, without the addition of chemicals.

The data indicate that through the biological side of the plant, the average effluent phosphorus concentration was 1.5 mg/L. The alum primary effluent had a phosphorus concentration of 1.3 mg/L. This would result in a plant effluent of 1.5 mg/L total phosphorus, which clearly would not be acceptable. It should be pointed out, however, that these data were collected for a two week period (rather than a one month average) and that during the sampling period several of the biological side primary and one of the secondary sedimentation basins were not in operation. The alum effluent had a particulate phosphorus concentration of 1.1 mg/L and the biological effluent had a particulate concentration of 1.1 mg/L which would result in a plant particulate phosphorus concentration of 1.1. Therefore, most of the plant phosphorus effluent was particulate, and the fact that the clarifiers were overloaded might be somewhat responsible.

The biological effluent consisted of 30 mg/L BOD_5 and 53 mg/L SS while the alum effluent consisted of 151 mg/L BOD_5 and 53 mg/L SS. Thus, the plant effluent, which would be 54 mg/L BOD_5 and 53 mg/L SS would also not meet the secondary treatment standards, based on the two weeks of field data.

A plot of phosphorus concentrations versus overflow rates for the primary sedimentation basin in which the alum and polymer were added is shown in Figure 45. The basin had a design of 1000 gallons per day per square foot (40.7 m^3/m^2/day). The points on the far right occurred during a storm. No distinct trends can be identified by the data.

Alum was added to the primary tank at a concentration of 3.7 mg/L Al^{+3}. The soluble phosphorus concentration in the influent was 1.1 mg/L and the total phosphorus was 3.8 mg/L. As summarized in Table 26 the resulting Al:P molar ratios on a soluble P and total P basis are 3.8 and 1.2, respectively. Jar tests conducted on the raw wastewater are shown in Figure 46 (unadjusted pH) and Figure 47 (pH adjusted to 6). Note that the data for an alum dosage of zero are for controls and do not match the initial data as settling had occurred in the jar test beakers. Also for Figure 47, alum was added to the samples and then the pH was adjusted to 6.0. The jar test

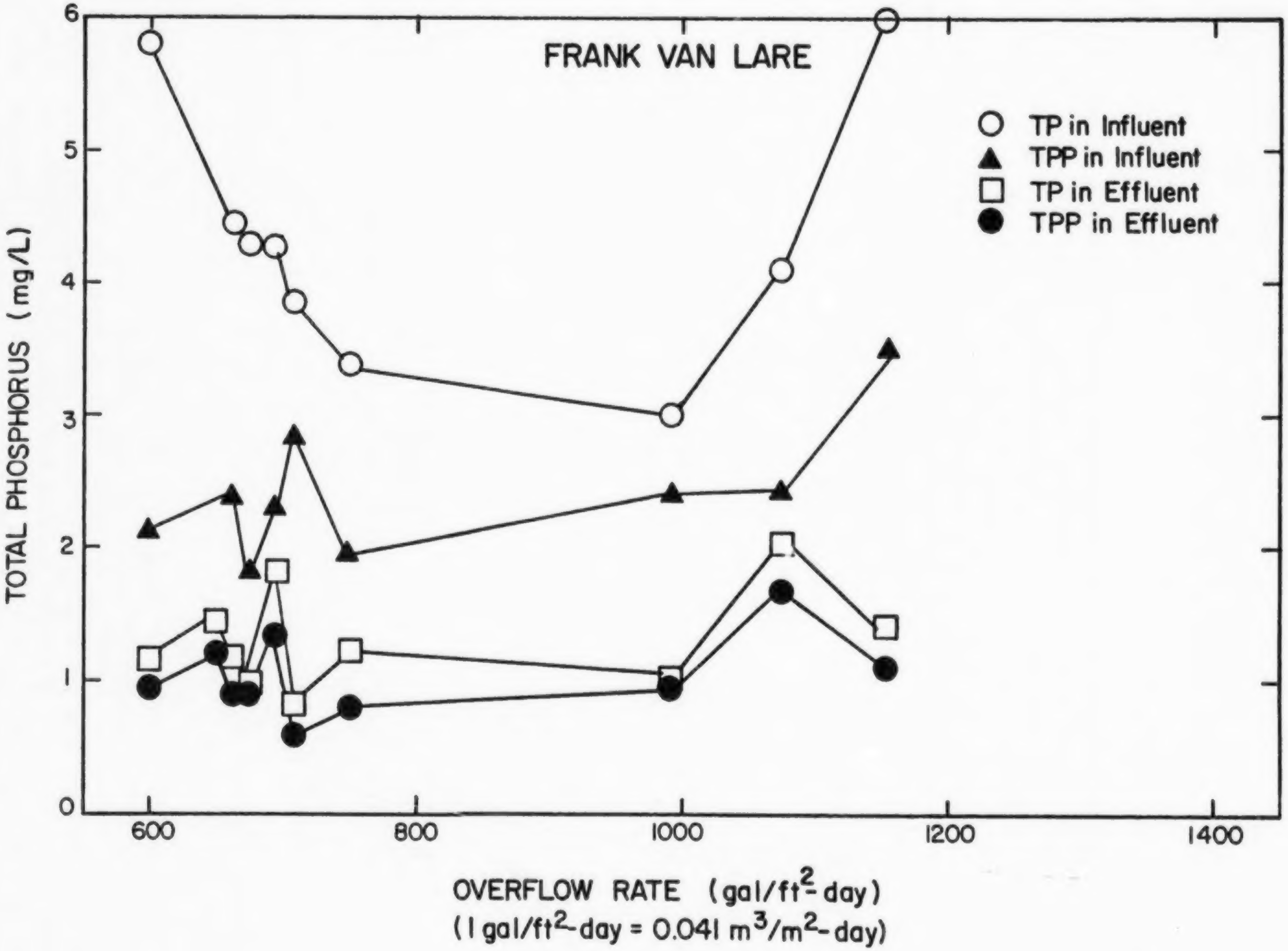

Figure 45. Phosphorus concentrations versus overflow rate of primary sedimentation unit - Frank Van Lare

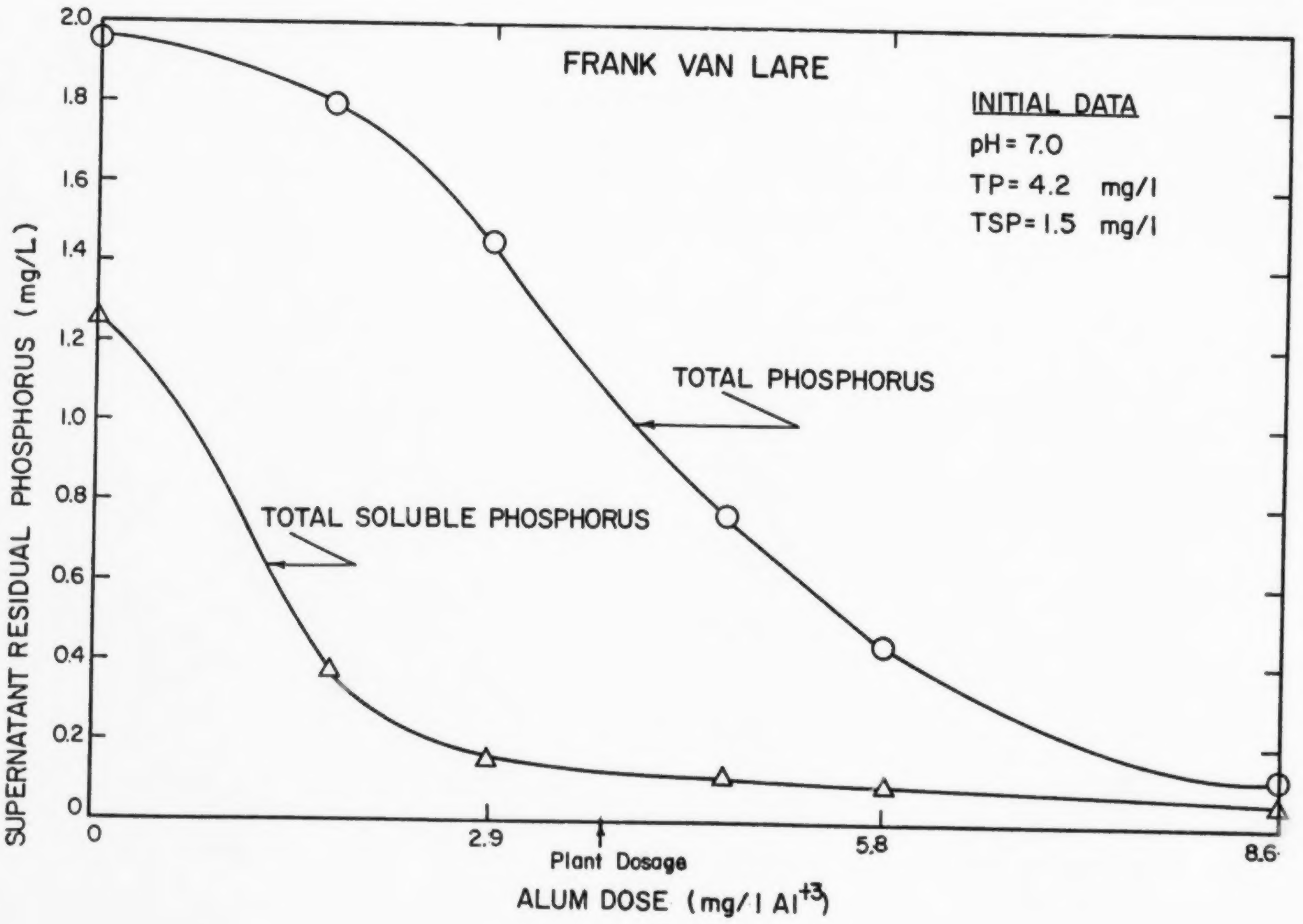

Figure 46. Jar test results (unadjusted pH) - Frank Van Lare

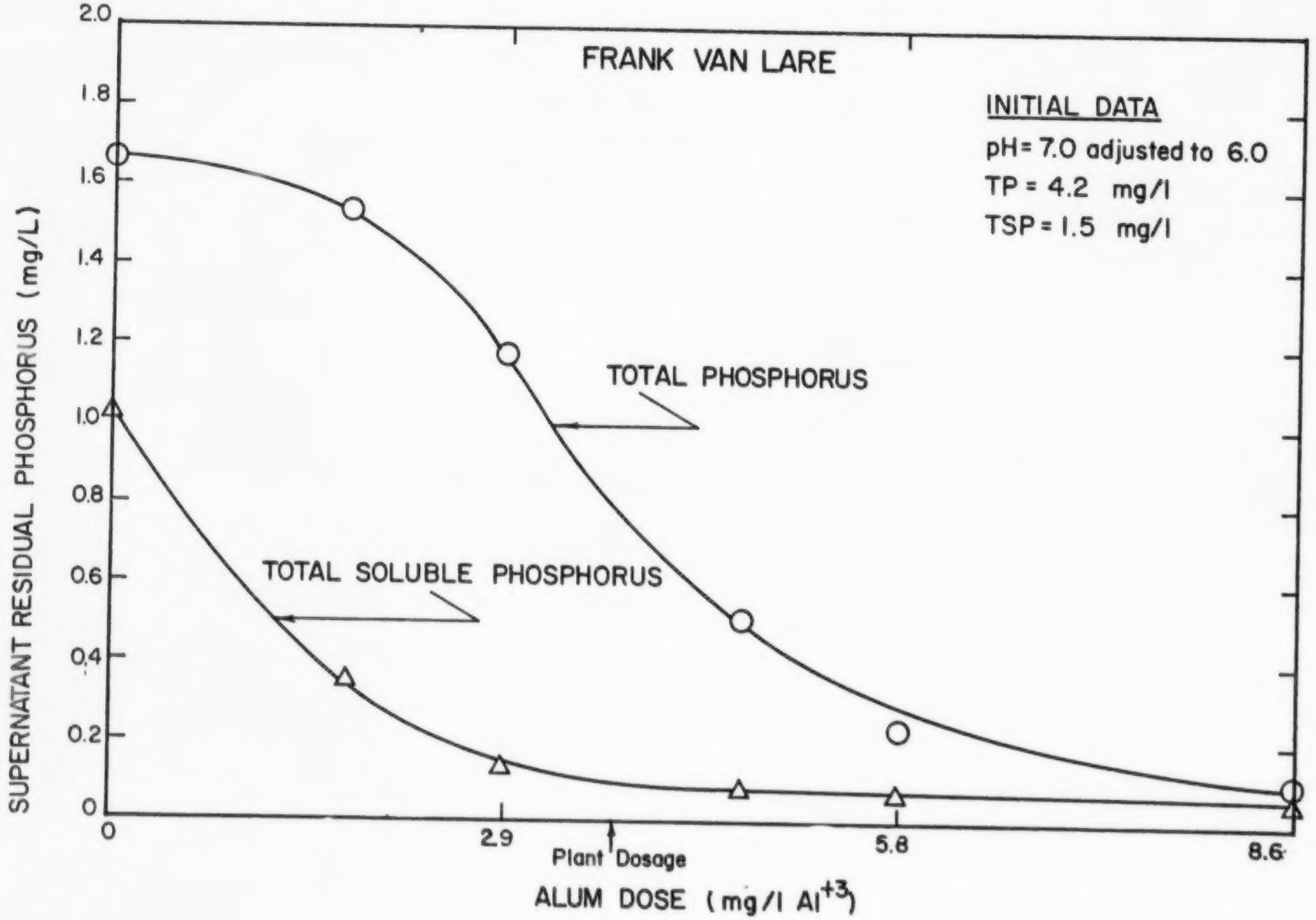

Figure 47. Jar test results (pH adjusted to 6) - Frank Van Lare

results confirm the plant performance data for P removal, indicating that the alum dosage being used is not effective in reducing the total P below 1 mg/L. This is because the alum is being added to raw wastewater; consequently, alum is being used to coagulate the solids of the raw wastewater as well as for P removal. No jar test experiments were performed using the polymer employed at the Van Lare plant. However, comparison of plant phosphorus data with jar test results indicate that a considerable fraction of the remaining phosphorus after treatment is particulate. This particulate P might be removed by increasing the alum dosage, lowering the pH, and/or optimizing the polymer dosage.

Alternatives to Meet a 0.5 mg/L Limit

Suggesting a feasible alternative approach for the Van Lare plant to meet a 0.5 mg/L effluent standard would be very difficult on the meager information available in this study. Because of the complex and unusual treatment approach currently being used and because of the final settling problems observed during the monitoring period, any phosphorus removal alternative suggestion would be highly speculative. Furthermore, any new approach would probably require significant alteration of the current operation and, quite likely, require additional capital expenditure.

It might be possible for the Van Lare plant to practice phosphorus removal in the same manner as the GCO plant. This approach would require biological treatment of the entire flow, with phosphorus removal being achieved by addition of liquid alum to the mixed liquor effluent from the aeration basins. The field data (Section 6) indicated an average value of 0.3 mg/L soluble phosphorus in the effluent from the biological side of the plant. Therefore, an alum dosage of 16 mg/L would be necessary for an Al:P molar ratio of 2:1. A polymer addition to the final clarifiers at a dosage of approximately 0.5 mg/L might also be necessary to ensure effective solids removal. Assuming costs of $0.056 per pound ($0.12/Kg) for alum and $1.32 per pound ($2.90/Kg) for polymer, the chemical costs would be $0.013/1000 gallons of $435,159 per year, based on an average daily flow of 102 mgd (3.86×10^5 m^3/day).

Based on the stoichiometric relationship between Al^{+3} and phosphorus, 33 lbs of aluminum phosphate sludge would be generated from phosphorus removal resulting in a cost of $0.003/1000 gallons treated for $96,592 per year (based on a unit cost of $158.22 per ton of dry solids process).

The capital expenses for adding the above phosphorus removal approach to secondary treatment at Van Lare are impossible to estimate at this time. Based on the field data it would appear that the final settling facilities at the plant are already overloaded. Any costs for upgrading the secondary sedimentation facilities could not be totally attributed to phosphorus removal. In order to assess the true investment necessary at the Van Lare plant to meet a 0.5 mg/L effluent phosphorus standard, a major study would have to be made to determine all the ramifications - such as available land, effect on pumping, sludge processing, etc. - which might result.

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Clarkson

APPENDIX A

QUESTIONNAIRE AND SURVEY WORK SHEET

Dear Sir:

At the present time, our Environmental Engineering group is working in cooperation with the United States Environmental Protection Agency on a project entitled, "Analysis of Phosphorus Removal in Great Lakes Basin Municipal Treatment Plants". This project involves an analysis of the costs and benefits pertaining to the establishment of regulations regarding the removal of phosphorus from municipal wastewater in the Great Lakes Basin in order to generate useful information for deciding upon final effluent regulations.

As part of this project, a survey is being conducted of municipal treatment plants larger than one MGD in the lower Great Lakes Basin in order to evaluate their treatment approach and plant operation; and to document their costs. Your answers to the enclosed questionnaire and any further information you could supply would help us greatly in regard to our survey.

We greatly appreciate your attention to this questionnaire, and please call me (315-268-6515) if you have any questions concerning this questionnaire or our project.

Sincerely,

Michael Switzenbaum
Assistant Professor
Department of Civil and
Environmental Engineering

Enclosures

CLARKSON COLLEGE, POTSDAM, NEW YORK, 13676

QUESTIONNAIRE

1. What is the location of your wastewater treatment plant? Please give complete mailing address, name of plant and stream receiving discharge.

2. What type of plant is it? (Examples: conventional activated sludge, extended aeration, contact stabilization, trickling filter, primary treatment, etc.)

3. What is the average daily flow and design flow at your plant?

4. What method of phosphorus removal is being practiced at your plant? Please be specific as to type of chemical used and point at which chemical is applied and any additional unit processes used in conjunction with phosphorus removal. (Example: Alum added to effluent from trickling filter between filter and secondary clarifier followed by filtration.

5. What are the average concentrations of phosphorus (both soluble and particulate) in the influent and effluent of your plant? What is the frequency of analysis (daily, weekly, etc.) and what is the sampling basis (grab, or composite)?

6. If the removal of phosphorus involves the use of chemicals, please indicate quantities used (indicate dosage).

7. Additional information.

PLEASE RETURN IN SELF-ADDRESSED STAMPED
ENVELOPE BY JULY 15, 1979.

APPENDIX A (continued)

WASTEWATER TREATMENT PLANT WORK SHEET

Plant Reference Numer __________ Source of Information __________________

1. Treatment plant name and address

2. Location

   a) Lake Basin:
   b) Regulatory region:
   c) County:
   d) City:
   e) Discharge site:

3. Type of plant

4. Phosphorus treatment approach

   a) Chemical(s) used:
   b) How much:
   c) Where in process:

5. Flow data

   a) Average daily flow
   b) Design flow

6. Influent and Effluent quality

   a) Influent: Total P __________ Soluble P ___________
   b) Effluent: Total P __________ Soluble P ___________
   c) Basis:

7. Annual phosphorus load (metric tons/year)

APPENDIX B

WASTEWATER PLANT PERFORMANCE DATA

WASTEWATER PLANT PERFORMANCE, MONTHLY AVERAGES, 1979*

		Monthly Average					
		Influent			Effluent		
Wastewater Treatment Plant	Flow (MGD)	BOD (mgO_2/L)	SS (mg/L)	TP (mg P/L)	BOD (mgO_2/L)	SS (mg/L)	TP (mg P/L)
Gates-Chili-Ogden							
January	14.1	108	133	4.7	7	13	0.80
February	12.5	112	120	4.6	6	13	0.70
March	16.5	80	89	3.9	10	13	0.96
April	15.5	89	91	3.6	5	10	0.90
Frank Van Lare							
February	92.1	148.0	114.8	2.64	24.9	22.1	0.98
March	124.9	134.5	109.1	3.01	32.0	42.1	0.99
April	117.2	144.9	108.7	2.13	33.2	26.7	0.75
May	93.1	195.9	133.7	2.94	33.1	30.7	1.04
June	88.0	187.1	134.5	2.86	27.4	25.5	0.82
Big Sister Creek							
January	5.14	102	99	2.4	2.5	2.3	0.7
February	4.13	91	91	2.7	2.5	2.9	1.0
March	5.77	88	88	2.5	2.5	4.6	0.7
April	5.10	61	70	2.0	1.8	2.4	0.7
May	2.89	130	181	4.9	1.8	2.8	0.7
June	2.54	199	271	6.4	1.4	4.1	0.8
Ely							
January	0.71	107	113	NA	4.1	2.4	0.395
February	0.76	146	159	NA	5.9	3.3	0.337
March	0.80	123	147	NA	7.4	6.0	0.305
April	1.31	87	121	NA	12.8	11.1	0.321
May	1.00	80	115	NA	9.6	4.1	0.180
June	0.98	58	69	NA	11.1	4.8	0.122

* From plant records

APPENDIX C

DATA FROM FIELD MONITORING STUDIES

RESULTS OF ANALYSES OF WASTEWATER FROM INTENSIVELY MONITORED WASTEWATER TREATMENT PLANTS, BY PLANT AND LOCATION WITHIN PLANT*

GATES-CHILI-OGDEN: RAW INFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	Al_t	Al_s	Flow
7/3	9:00 AM	G	7.2	216	4.13	1.57	1.39	2.56	2.39	112	370					3.67
7/3	9:00 PM	C	7.8	213	3.82	1.17	1.09	2.50	1.50	184	366	195		.551	<.012	3.72
7/4	5:30 PM	C	7.5	209	5.03	2.54	2.06	2.46	3.34	143	299		25.1			3.25
7/5	5:15 PM	C	7.8	214	6.02	2.28	1.72	3.40	2.68	177	395	195	28.2	.339	<.012	3.60
7/5-7/6	1:15 AM	C	7.7	207	7.01	2.66	2.02	4.13	3.18	181	469					3.50
7/6	8:30 PM	C	7.8	210	5.79	2.34	1.76	3.50	3.00	159	422		29.6			3.70
7/7	8:15 AM	C	7.8	210	5.72	1.08	0.92	4.68	2.34	128	278	170		.332	.050	2.71
7/7	4:15 PM	C	7.8	216	6.65	2.12	1.46	4.48	2.12	168	402		16.2			3.40
7/8-7/9	7:00 AM	C	7.8	211	7.03	2.12	1.64	4.00	2.06	101	324			.536	<.012	2.69
7/9	6:15 PM	C	7.8	220	7.09	2.76	2.00	4.02	2.68	222	443					3.89
7/10	8:00 PM	C	7.8	218	8.35	1.70	1.34	6.46	2.18	113	322		21.1	.229	<.012	2.65
7/11	10:00 PM	C	7.7	211	8.64	3.66	3.02	4.46	3.00	295	532		28.7	.145	.015	3.81

APPENDIX C (continued)

GATES-CHILI-OGDEN: PRIMARY EFFLUENT

Date	Time of Collection	Sample Type**	PH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	Al_t	Al_s	Flow
7/3	9:00 AM	C	7.5	211	4.98	1.47	1.70	3.60	1.92	76	319					
7/10	8:00 PM	C	7.7	210	5.34	1.56	1.12	4.13	2.74	61	303		22.7	.337	.041	
7/11	10:00 PM	C	7.7	210	6.08	1.52	2.00	4.28	2.94	67.9	248		27.6	.127	<.012	

GATES-CHILI-OGDEN: SECONDARY EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	Al_t	Al_s	Flow
7/3	9:00 AM	C	7.2	128	1.36	0.76	0.61	0.60	0.36	8.3	103					1.45
7/3	9:00 PM	C	7.2	121	1.06	0.57	0.48	0.50	-	11.6	40.4	15		0.88	.070	3.41
7/4	5:30 PM	C	7.2	121	0.78	0.42	0.48	0.32	0.09	9.6	45.1		2.13			2.39
7/5	5:15 PM	C	7.5	96	0.32	0.21	0.22	0.14	0.14	7.9	43.3	17	1.7	0.418	.021	2.76
7/5- 7/6	1:15 PM	C	7.4	119	0.43	0.48	0.31	0.15	0.07	12.5	33.8					2.73
7/6	8:30 PM	C	7.2	117	0.52	0.34	0.34	0.17	0.10	9.7	35.7		5.1			3.14
7/7	8:15 AM	C	7.4	115	0.52	0.34	0.35	0.24	0.12	9.6	44.4	16.5		0.973	<.012	1.29
7/7	4:15 PM	C	7.6	108	0.59	0.34	0.35	0.22	0.10	7.4	60.2		3.9			2.37
7/8- 7/9	7:00 AM	C	7.8	115	0.69	0.42	0.35	0.37	0.42	9.2	54.5			1.587	.012	1.02
7/9	6:15 PM	C	7.4	108	0.51	0.27	0.32	0.20	0.14	9.5	41.4					-
7/10	8:00 PM	C	7.6	113	0.88	0.38	0.37	0.49	0.31	12.2	50.8		5.9	0.433	<.012	1.67
7/11	10:00 Pm	C	7.9	124	1.32	0.54	0.30	0.74	0.28	12.8	50.8		5.5	0.335	.027	3.31

APPENDIX C (continued)

FRANK VAN LARE: RAW INFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	Al_t	Al_s	Flow
7/17	12:00 AM	C	7.3	142	3.44	1.93	1.73	1.02	0.63	130	416	255	17.3			74.20
7/18	12:00 AM	C	7.4	164	4.36	2.43	2.11	1.51	1.09	181	536	228		.531	<.012	79.20
7/19	12:00 AM	C	7.3	165	3.04	1.53	1.44	1.18	0.95	143	359	174	16.9			75.30
7/20	12:00 AM	C	7.3	155	3.31	1.90	1.24	1.44	1.23	132	372	159		.280	<.012	84.10
7/21	12:00 AM	C	7.3	171	6.90	4.15	3.13	2.01	1.73	470	735	217	27.5			72.80
7/22	12:00 AM	C	6.6	128	3.40	1.67	1.51	1.27	0.96	161	457	295		.401	.012	67.40
7/23	12:00 AM	C	7.2		3.23	1.87	1.67	0.90	0.60	173	448	280	17.9		-	77.40
7/24	12:00 AM	C	7.3	138	3.47	1.97	1.50	1.01	0.77	172	372	164		-	-	120.0
7/25	12:00 AM	C	7.6	135	4.10	3.25	2.49	0.60	0.46	127	448	195	20.3		-	130.1
7/26	12:00 AM	C	7.2	146	2.85	2.08	1.86	0.42	0.18	170	337	149		.226	<.012	111.0

FRANK VAN LARE: ALUM EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	Al_t	Al_s	Flow
7/17	12:00 AM	C	7.4	97	1.13	0.90	0.95	0.08	0.00	38.5	222	157	12.1			
7/18	12:00 AM	C	6.9	81.8	0.79	0.59	0.65	0.17	0.03	42.4	198	139		.822	.031	
7/19	12:00 AM	C	6.8	92.6	0.98	0.78	0.67	0.17	0.02	32.0	245	157	15.0			
7/20	12:00 AM	C	6.9	107	1.23	0.79	0.81	0.13	0.02	42.3	276	168		.859	.047	
7/21	12:00 AM	C	7.0	119	1.43	1.17	1.03	0.14	0.14	51.8	261	178	15.0			
7/22	12:00 AM	C	7.0	108	1.17	0.96	0.87	0.04	0.00	51.5	207	123		.389	<.012	
7/23	12:00 AM	C	7.1	-	1.86	1.55	1.50	0.08	0.00	76.5	286	196	14.5			
7/24	12:00 AM	C	7.0	97.8	2.04	1.73	1.56	0.15	0.03	73.0	278	147				
7/25	12:00 AM	C	7.4	97.2	1.41	1.20	0.98	0.08	0.02	61.5	226	139	12.8			
7/26	12:00 AM	C	6.9	96.3	1.04	0.96	0.83	0.03	0.01	52.0	179	103		.428	<.012	

APPENDIX C (continued)

FRANK VAN LARE: BIOLOGICAL EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	Al_t	Al_s	Flow
7/17	12:00 AM	C	7.6	116	1.79	1.01	0.84	0.63	0.85	50.5	94.0	38	4.0			
7/18	12:00 AM	C	7.5	118	1.74	1.28	1.10	0.32	0.24	66.0	115	43		.448	<.012	
7/19	12:00 AM	C	7.5	119	2.27	1.75	1.42	0.42	0.34	78.5	113	44	5.7			
7/20	12:00 AM	C	7.6	123	2.73	1.82	1.47	0.90	0.82	74.0	115	45		.280	.014	
7/21	12:00 AM	C	7.5	117	0.77	0.45	0.40	0.28	0.20	28.0	62.1	16	2.1			
7/22	12:00 AM	C	7.7	113	0.49	0.37	0.33	0.09	0.01	17.0	54.5	11		.448	.022	
7/23	12:00 AM	C	7.6	-	0.60	0.43	0.30	0.13	0.05	25.5	48.9	9	2.5			
7/24	12:00 AM	C	7.7	117	0.78	0.57	0.41	0.18	0.09	30.0	60.2	65		-		
7/25	12:00 AM	C	7.5	98.6	3.06	2.78	2.03	0.36	0.10	119	141	22	7.65			
7/26	12:00 AM	C	7.4	116	0.98	0.91	0.68	0.09	0.03	39.5	75.2	10		.472	.035	

BIG SISTER CREEK: RAW INFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Fe_t	Fe_s	Flow
7/30	8:00 AM	C	7.5	214	5.08	2.43	1.28	2.08	1.44	128	310		22.3				.724
7/30	11:00 PM	C	7.5	254	7.08	3.52	3.84	2.51	-	255	545			0.00	5.246	.172	.954
7/31	5:30 PM	C	7.1	259	10.16	6.52	5.85	2.70	1.94	429	562		41.1				.923
8/1	4:51 PM	C	7.3	223	9.19	6.26	7.34	2.00	1.44	390	512			-	12.241	.172	1.153
8/2	8:15 PM	C	7.3	207	5.43	3.65	3.31	1.43	0.78	175	322		21.8				.826
8/2	4:30 PM	C	7.3	255	8.06	5.76	4.33	1.92	1.02	240	493			-	6.557	.172	.979
8/2- 8/3	12:30 AM	C	7.3	229	5.64	3.09	2.79	2.19	1.39	251	442			-			.987
8/5	8:00 AM	C	7.4	223	4.45	2.40	2.25	1.86	1.21	176	292		22.3				.796
8/5- 8/6	12:30 AM	C	7.4	252	6.45	2.80	2.62	3.27	2.47	184	387	133		-	3.060	.215	.905
8/6	6:15 PM	C	7.4	270	7.96	4.78	4.28	2.45	1.47	293	384	127	37.6				.969
8/7	8:00 AM	C	7.4	205	3.98	1.81	2.01	1.55	1.15	111	228			-			.806
8/7	12:00 AM	C	7.3	229	11.07	11.84	6.38	2.42	2.10	670	1062		44.9				1.163
8/8- 8/9	7:00 AM	C	7.4	213	4.04	2.28	1.92	1.59	0.75	125	260						.893

APPENDIX C (continued)

BIG SISTER CREEK: SECONDARY EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Fe_t	Fe_s	Flow
7/30	8:00 AM	C	7.4	105	2.36	0.16	0.15	2.21	2.04	7.1	52.7		1.09				
7/30	11:00 PM	C	7.3	101	2.49	0.20	0.24	2.32	2.03	7.7	41.4			16.5	.267	<.12	
7/31	5:30 PM	C	7.3	109	2.33	0.19	0.15	2.11	1.94	11.9	52.7		0.86				
8/1	4:15 PM	C	7.4	116	1.87	0.13	0.17	1.75	1.39	10.7	52.7			14.0	.229	<.12	
8/2	8:15 PM	C	7.4	126	2.15	0.20	0.14	1.97	1.57	7.6	52.7		0.84				
8/2	4:30 PM	C	7.7	126	2.08	0.16	0.12	1.94	1.56	7.3	37.6			9.6	.533	<.12	
8/2-8/3	12:30 AM	C	7.6	129	2.09	0.17	0.14	1.92	1.48	8.5	54.5			12.1			
8/5	8:00 AM	C	8.3	134	2.28	0.21	0.14	2.15	1.80	7.1	41.4		0.86				
8/5-8/6	12:30 AM	C	7.4	122	2.42	0.25	0.12	2.27	1.87	7.7	33.9	4.1		14.1	.457	<.12	
8/6	6:15 PM	C	7.5	106	2.65	0.12	0.11	2.53	2.14	5.4	58.3	3.8	0.75				
8/7	8:00 AM	C	7.3	110	2.56	0.13	0.11	2.49	2.16	7.2	28.2			16.4			
8/7	12:00 AM	C	7.4	114	2.40	0.15	0.17	2.22	2.28	10.7	48.9		0.98				
8/8-8/9	7:00 AM	C	7.3	142	1.83	0.14	0.14	1.87	1.30	9.2	41.4						

BIG SISTER CREEK: SOLIDS CONTACT CLARIFIER EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Flow
8/6	9:30 PM	G			0.32	0.19	0.19	0.13	0.06					0.25	
8/6	12:00 AM	C			0.39	0.23	0.23	0.13	0.06					0.29	
8/7	12:00 AM	C			0.33	0.19	0.18	0.19	0.12					0.30	
8/8	12:00 AM	C			0.36	0.14	0.12	0.19	0.09					0.21	

APPENDIX C (continued)

BIG SISTER CREEK: FILTERED EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Fe_t	Fe_s	Flow
7/30	8:00 AM	C	7.8	103	1.03	0.13	0.13	0.94	0.84	3.9	28.2						
7/30	11:00 PM	C	7.2	90	1.01	0.11	0.05	0.96	0.91	3.5	31.9			23.1	.19	<.12	
7/31	5:30 PM	C	7.4	92	1.00	0.05	0.06	0.87	0.75	3.2	33.9		0.48				
8/1	4:15 PM	C	7.5	96	1.12	0.09	0.05	1.04	0.89	2.2	24.4			13.1	<.12	<.12	
8/2	8:15 PM	C	7.4	106	1.12	0.06	0.06	1.07	0.92	1.8	35.7		0.39				
8/2	4:30 PM	C	7.5	105	0.96	0.04	0.03	0.93	0.74	1.2	32.0			9.1	.305	<.12	
8/2-8/3	12:30 PM	C	7.3	106	0.94	0.03	0.04	0.83	0.71	1.3	33.9			10.6			
8/5	8:00 AM	C	7.6	113	1.04	0.10	0.04	0.91	0.85	1.5	37.6		0.49				
8/5-8/6	12:30 AM	C	7.3	107	0.96	0.05	0.04	0.99	0.75	1.8	16.9	2.2		11.1	<.12	.129	
8/6	6:15 PM	C	7.2	89.6	0.76	0.04	0.04	0.74	0.50	0.6	22.6	2.2	0.36				
8/7	8:00 AM	C	7.1	89.6	0.68	0.03	0.02	0.65	0.50	1.2	20.7			13.7			
8/7	12:00 AM	C	7.4	93.6	0.87	0.02	0.04	0.88	0.84	1.6	28.2		0.35				
8/8-8/9	7:00 AM	C	7.4	120	0.79	0.04	0.02	0.75	0.61	1.8	33.9						

APPENDIX C (continued)

ELY: RAW INFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Al_t	Al_s	Flow
9/13-9/14	8:00 AM	C	8.8	171	2.57	1.52	1.04	1.13	C.87	83	184						.185
9/14	4:30 PM	C	8.2	186	4.64	2.38	1.99	2.03	1.33	180	354		18.7		2.77	.206	.268
9/14-9/15	12:30 AM	C	7.5	148	2.84	1.79	1.44	1.01	0.73	106	241			.06			.237
9/15	12:00 AM	C	7.2	137	3.58	2.49	1.93	0.99	0.73	121	258		17.8		0.846	.018	.231
9/16	6:30 PM	C	7.4	151	3.73	2.38	1.67	1.36	0.92	115	329			.08			.237
9/17	6:00 PM	C	8.1	172	4.40	2.54	1.65	1.95	1.27	153	348				1.653	.174	.259
9/18	8:00 AM	C	7.3	124	2.43	2.60	1.84	0.37	0.30	78	151	96	10.2				.168
9/20	8:00 AM	C	7.4	154	6.97	4.78	4.56	2.02	1.61	212	416	266	32.8	.16	1.048	<.012	.166
9/20	12:00 AM	C	7.1	136	3.66	2.12	1.79	1.33	0.99	116	228		15.6				.209
9/21	6:00 PM	C	8.7	188	4.41	1.85	1.00	2.72	1.45	122	333			.12			.255
9/22	9:00 AM	C	7.2	112	2.20	-	0.96	0.86	0.63	64	147			.16	0.664	.016	.176
9/22	12:00 AM	C	7.9	153	3.79	2.19	1.93	1.40	1.09	123	246						.226

ELY: SECONDARY EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Al_t	Al_s	Flow
9/13-9/14	8:00 AM	C	7.1	144	1.02	0.93	0.86	0.02	1.01	39	959						
9/14	4:30 PM	C	7.3	145	1.64	1.95	1.31	0.03	1.01	62	122		14.6		0.831	.026	
9/14-9/15	12:30 AM	C	7.2	139	1.45	1.33	1.10	0.02	0.00	56	119			0.90			
9/15	12:00 AM	C	7.3	136	1.47	1.48	1.13	0.02	0.00	53	134		14.0		1.392	.022	
9/16	6:30 PM	C	7.3	125	1.70	1.66	1.43	0.05	0.00	58	154			1.26			
9/17	6:00 PM	C	7.2	130	1.87	1.74	1.54	0.03	0.01	65	130				0.809	.044	
9/18	8:00 AM	C	7.2	123	1.20	1.13	1.02	0.02	0.00	42	790	32.9	14.9				
9/20	8:00 AM	C	7.3	111	1.88	1.67	1.66	0.05	0.01	48	105	37.2	14.9	1.33	.617	.048	

APPENDIX C (continued)

ELY: SECONDARY EFFLUENT (continued)

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Al_t	Al_s	Flow
9/20	12:00 AM	C	7.2	149	2.24	2.00	1.77	0.06	-	68	151		14.6				
9/21	6:00 PM	C	7.4	143	2.55	2.30	1.94	0.04	0.02	63	134			0.50			
9/22	9:00 AM	C	7.4	124	1.38	1.27	1.16	0.03	0.00	45	940				0.991	.050	
9/22	12:00 AM	C	7.5	139	2.21	2.00	1.88	0.03	0.01	59	111						

ELY: FILTERED EFFLUENT

Date	Time of Collection	Sample Type**	pH	Alk	TP	TPP	NaOH-P	TSP	SRP	SS	COD	BOD	TKN	NOx	Al_t	Al_s	Flow
9/14	8:00 AM	G	7.2	116	0.46	0.35	0.36	0.05	0.02	12.7	71.5						
9/14	4:30 PM	C	7.5	126	0.38	0.34	0.31	0.02	0.00	7.5	60.2		11.3		0.546	.043	
9/14- 9/15	12:30 AM	C	7.4	131	0.34	0.30	0.25	0.02	0.00	11.9	52.7			1.04			
9/15	12:00 AM	C	7.4	138	0.41	0.34	0.31	0.02	0.00	9.5	94.0		12.0		1.124	<.012	
9/16	6:30 PM	C	7.3	121	0.47	0.42	0.39	0.09	0.01	13.4	77.1			1.41			
9/17	6:00 PM	C	7.3	115	0.43	0.39	0.35	0.03	0.01	12.7	77.1	16.2			0.799	.037	
9/18	8:00 AM	C	7.6	124	0.49	0.42	0.44	0.03	0.01	12.7	58.3	13.2	10.9				
9/20	8:00 AM	C	7.2	103	0.75	0.65	0.71	0.05	0.02	14.2	56.4		12.8	1.78	0.539	.066	
9/20	12:00 AM	C	7.4	124	0.92	0.78	0.75	0.05	0.03	18.7	73.3		13.2				
9/21	6:00 PM	C	7.4	120	0.75	0.66	0.61	0.04	0.02	13.3	63.9			2.07			
9/22	9:00 AM	C	7.4	136	0.76	0.70	0.64	0.04	0.02	16.7	69.6			1.93	0.927	.044	
9/22	12:00 AM	C	7.3	127	0.57	0.49	0.47	0.03	0.01	12.5	56.4						

* Concentrations are given in mg/L of analate as element, e.g., mg P/L, with exception of Alk which is mg$CaCO_3$/L and pH. Flow is given as million gallons during the sampling period. (1 mgd = 3,785 m^3/d).

** Sample type: G = grab, C = composite

All composite samples were taken over an 8 hour period, with the exception of those at all sampling sites at Frank Van Lare and those from the Solids Contact Clarifier at Big Sister Creek, which were taken over a 24 hour period.

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